THE SPECTRE OF THE BROCKEN.

THE BROCKEN IS THE HIGHEST POINT OF THE HARZ MOUNTAINS (3,740 FEET); IT IS SITUATED IN PRUSSIAN SAXONY, SOME TWENTY MILES W.S.W. OF HALBERSTADT. THE "SPECTRE," WHICH IS A MUCH MAGNIFIED IMAGE OF THE BEHOLDER, IS THROWN ON THE MIST BANK WITH WHICH THE MOUNTAIN IS USUALLY SHROUDED AT SUNRISE AND SUNSET.

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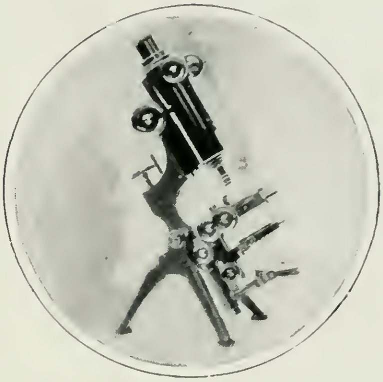
POPULAR SCIENCE .



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ILLUSTRATIONS.

COLOURED PLATES.

CASSELL'S POPULAR SCIENCE.

SHADOWS.

By WILLIAM ACKROYD, F.I.C.

WHO has not glanced at his shadow cast by the sun, and with curious eye made note of its form and proportions, always grotesque, and at one time gigantic in its dimensions, at another dwarfed to the representation of a pigmy? As children we may have chased it, or like Alexander's horse, Bucephalus, been frightened by it; as boys, it may have been a source of dissatisfaction, more especially when some feature of clothing or gait has been exaggerated; and as men we have doubtless altogether ignored it; but with nothing have we become so familiar, and nothing have we come to regard as so unreal, changeable, and devoid of the properties which pertain to tangible bodies. Because of these qualities its name is in constant use metaphorically. A Government corrupt to its core is described by the historian as a shadow: the thin, pale man, wasted by disease, we speak of as the shadow of his former self; and to a Tennyson, concentrating a million years into a moment,

> "The hills are shadows, and they flow
> From form to form, and nothing stands."

It is of this symbol of the changeable and unreal that we have to speak, and we intend to tell of remarkable as well as common shadows, how they are produced, and what they are like.

Shadows are the result of the great law that light proceeds through a homogeneous medium in straight lines. Hence, when an opaque body is held in the way of light there is darkness, or shadow, behind it, and the form of the shadow projected on to any screen placed to receive it is determined by the form of that section of the obstructing body which is at right angles to the direction of the light rays; hence the shadow of a ball is a dark circle, and if one were to bend the bare arm at the elbow and the hand at the wrist, as in Fig. 1, the shadow would be a fair representation of a swan.

These hand-shadows have always been a source of keen delight to children, because of the number of shapes one may represent by various dispositions of the hands when held up not far from the gaslight, and, perhaps, because the black

FIG. 1.—A SHADOWY SWAN.

This may easily be made by the arm, if the elbow and wrist are bent as shown.

moving things on the wall may be made a caricature of the real. Heads of animals of all sorts may be exhibited and made to open their mouths or prick their ears at pleasure, and the enjoyment reaches its height when by the judicious disposition of lights, and the co-operation of two

friends of mature years, a negro and a Red Indian are exhibited jabbering in unknown tongues (Figs. 2 and 3).

Natural shadows assume a position of some importance, for wherever light can reach there they are sure to be produced. The shadows of lunar mountains, or of Jupiter's satellites, are interesting sights to the astronomer, and here below our own mountain shadows at times are remarkable things to see. Perhaps one of the most extraordinary mountain shadows is that of Adam's Peak in Ceylon. The peak rises abruptly from the low country to some 7,420 feet above the level of the sea, commanding a fine view of the island scenery to the south-west and north-west for a distance of fifty miles or more. The phenomenon of the shifting shadow of the mountain is thus described by those who have seen it. It appears at sunrise, an enormous elongated shadow projected to the westward over land and sea. As the sun rises higher the shadow approaches the mountain rapidly, and appears at the same time to rise above the spectator in the form of a gigantic pyramid of shadow, a veil of darkness suspended in the air. Each instant it becomes more distinct, until suddenly it seems to fall back on the observer, and the next moment it is gone. It is a peculiar shadow manifestation of mirage.

FIG. 2.—HAND SHADOWS: A NEGRO'S HEAD.

Shadows, as we generally see them, are areas of darkness on the surfaces of solids; but smoke and dust particles, which readily reflect light, render shadows very distinct. In a smoky atmosphere the shadow of a house is seen in the air as well as projected on the road, the distinct line of division between the light and shadow being readily traceable. Mist is also a very efficient shadow-shower, and probably the moving veil of darkness seen in the case of Adam's Peak is thrown on the morning mist which has not yet been dispelled by the solar heat rays; and similarly, in the case of the remarkable shadow known as the Spectre of the Brocken, the dense and hazy atmosphere surrounding the mountain summit forms a good shadow ground at sunrise and sunset. (*See* Coloured Plate.)

The Brocken, one of the loftiest of the Harz Mountains (3,740 feet), has from the earliest times enjoyed pre-eminence as the seat of the marvellous. Here in times past the timorous peasant was wont to see, at break of day, black, gigantic forms, more fear-inspiring than any Oriental genii ever were. In his benighted state of mind he could but refer the effects he saw to magic, to that wonderful occult influence which enabled a Michael Scott to cleave a mountain and do other marvellous acts. And now the traveller is shown on the summit of the Brocken the Sorcerer's

FIG. 3.—HAND SHADOWS: A RED INDIAN.

By means of a little arrangement of the light the shadows shown in Figs. 1, 2, and 3 may easily be made.

Chair and the Altar, huge blocks of granite; he stoops to drink at the Magic Fountain, a crystal spring; or, maybe, plucks up the anemone of the Brocken, and is told it is the Sorcerer's Flower. His next great desire is to see the Spectre of the Brocken, for his brain being uncobwebbed with ancient superstition, he perceives clearly that the spectre must be some natural phenomenon. He is successful in his efforts, and sees a most remarkable group of shadows of himself and comrades. Looking westward while the sun is rising, he observes gigantic forms of darkness which mimic every movement that is made: they seem far off, and yet are probably close at hand, and ere long have completely vanished.

FIG. 4.—SHADOWS IN THE AIR: A RAINBOW AS SEEN FROM A BALLOON.

Notice that the circular rainbow is below the balloon, also that the shadow of the car of the latter is visible in the centre of the rainbow.

When a person's shadow is projected on to mist particles an accompanying effect is at times observed which might nearly have been predicted—the head of the shadow is surrounded by very large crowns of colour. It will be noted that in such a case we have precisely the same conditions as for seeing rainbows—viz. the sun behind, and the effect to be observed fair in front. The reader will have no difficulty in seeing that if the observer's shadow could be cast in the same plane as the rainbow, the head of the shadow would occupy the exact centre of the gorgeous circle. It is seldom that complete circular rainbows are seen, but at such times a shadow of the observer is in the centre. Fig. 4 illustrates a case of this kind, where M. Tissandier, having ascended in a balloon above the clouds, saw a circular rainbow projected on the vapoury atmosphere below, and right in the centre the shadow of the car and its occupants. The phenomenon which is known as "Ulloa's Circle" (Fig. 5) would appear to be somewhat of the same nature, and the following are the circumstances under which MM. Ulloa and Bouguer saw it. During their stay in the Pinchincha they were one morning at daybreak on the

summit of the Pambamarca. The mountain top was covered with a dense fog, which was gradually dispersed by the rising sun. While they were watching this gradual disappearance of fog and light vaporous clouds, one of the travellers, on turning his back to the rising sun, saw the appearance portrayed in Fig. 5. Standing apparently at a distance of twelve feet was an image of himself, surrounded by three concentric rings, shaded with different colours, while round the whole was a fourth ring of one colour only. The figure mimicked every movement of the observer, the rings keeping the shadow of the head as a common centre. It is a singular thing that each of the travellers saw only himself, and not a group, as in the balloon ascent we have just mentioned.

When two lights send their rays towards the obstructing body, a couple of shadows are thrown on to the ground, and one generally appears blacker than the other. An exact comparison of the two shadows may lead to precise information respecting the relative merits of the two lights themselves (Fig. 6). Since a perfect shadow is the total absence of light, it is apparent that the perfect shadow of *b*, produced by the lights *a* and *c*, ought to have the same degrees of blackness. But the shadows *a′* and *c′* are each illuminated respectively by the lights *c* and *a*, and are consequently much lighter than the perfect shadows would be. It is quite clear, therefore, that if the lights *a* and *c* were the same distance from the light obstructor *b*, and if, moreover, there were a difference of illuminating power in *a* and *c*, then there would be a difference of blackness in the shadows, that shadow being the blacker which was illuminated by the weaker light, and in the case in point, *c* would be the weaker light. More precise information still could be obtained about the relative merits of the lights *a* and *c* by utilising the law of inverse squares, which has been already explained in another place.*

FIG. 5.—ANOTHER CIRCULAR RAINBOW: ULLOA'S CIRCLE.

We know that three surfaces of equal area placed at distances—

1, 2, and 3

* "Getting Hot," CASSELL'S POPULAR SCIENCE, Vol. I., p. 512.

from the candle receive amounts of light which may be expressed in figures, as—

1, 1-4th, and 1-9th,

respectively.

Precise information may, therefore, be obtained regarding the respective illuminating powers of two lights by utilising these facts. It was done by Count Rumford, and his method may be thus simply followed.

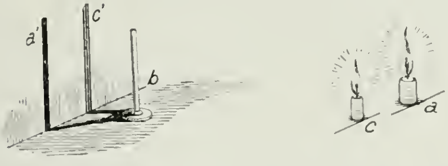

FIG. 6.—THE DEPTH OF THE SHADOW DEPENDS UPON THE INTENSITY OF THE LIGHT.

c, a, candle lights; b, the object to be shadowed; a' and c', shadows.

Suppose we required to know the relative illuminating powers of a paraffin oil lamp and a common candle, we might proceed in the following homely fashion (Fig. 7):—Pin a sheet of white paper against the wall as a screen to catch the shadows; place a rod or stick in the neck of a bottle, *b*, for a shadow producer; and have a tape measure, *t*, with the free end of the tape pinned down at the bottom of the paper, so that distances from the screen may be readily measured. Now bring the lights to be tested alongside the tape, and by putting the stronger light farther from the screen than the other the distances may be so adjusted that the shadows *a'* and *c'* are both of the same degree of blackness. Suppose these are the distances of the lights from the screen:

Candle	7 feet.
Oil lamp	12 ,,

The squares of the numbers, viz. 49 and 144, would express the relative illuminating powers of the two lights; whence it would appear that the oil lamp is not far short of being equal in illuminating power to three such candles, as

$$\frac{7^2}{12^2} = \frac{49}{144} = \frac{1}{2{\cdot}93}.$$

Here we have a side to the subject of practical bearing. In London, under the supervision of the County Council, the illuminating power of the gas is periodically tested to see that the amount of light given off comes up to the required legal standard. Other cities and towns do the same thing. And, indeed, the legislature regards this matter of such importance that it specially enacts that where the illuminating power of the gas is not properly looked after, a few ratepayers, on making representations to the magistrates, can compel the authorities to see that it is done. How is it done? Some idea can be given from the following short description of the use of the *photometer*, or light-measurer. The gas, in the first place, is burnt from an Argand burner at the rate of five cubic feet per hour, the supply being regulated by meter. The light is compared with the light of a couple of sperm candles burning at the rate of 120 grains per hour. The two sources of

FIG. 7.—COUNT RUMFORD'S SHADOW TEST FOR LUMINOSITY.

A sheet of white paper is pinned to the wall; b, is a bottle containing a rod; a, the candle; c, an oil lamp; t, a measuring tape; a', c' are shadows. The distance of a and c from b is adjusted so that the shadows are of the same degree of blackness.

light are at opposite ends of a graduated bench, on which slides a box containing a paper disc with the central part greased. As the disc is moved backwards and forwards, a spot is found between the two sources of illumination where the quantities of light coming in opposite directions are equal—*i.e.* the greased circle is neither lighter nor darker than the rest of the paper. An application of the law of inverse squares now enables the two sources of light to be quantitatively compared. In practice, the candles seldom burn at regulation rate, nor does the gas pass through the meter at a speed of five cubic feet per hour, and consequently it is part of the business of the gas examiner to apply corrections. A pentane photometer is shown in Fig. 8.

Shadow phenomena are somewhat different when the sources of light are a luminous point and a luminous surface respectively, as, *e.g.*, a brilliant star and the sun. When a point of light is used, the usual black shadow is fringed with colours, which form a gradation between the darkness within and the bright space without: but when a surface of light is employed, the complete shadow, or *umbra*, is surrounded by a less complete shadow, or *penumbra*. As we have said, a brilliant star or planet is an example of a point of light, and Sir John Herschel has observed that Venus, when at its greatest brightness, produces a shadow bordered with coloured fringes, if the shadow be cast upon a white screen within a one-windowed room, and under favourable circumstances as to twilight. For experiments of this sort an artificial point of light may be thus produced :—Admit the parallel rays of the sun into a dark room through a hole in the shutter, and then bring the rays together by means of a lens of short focus. The small image of the sun which is thus formed at the focus is a brilliant point of light.

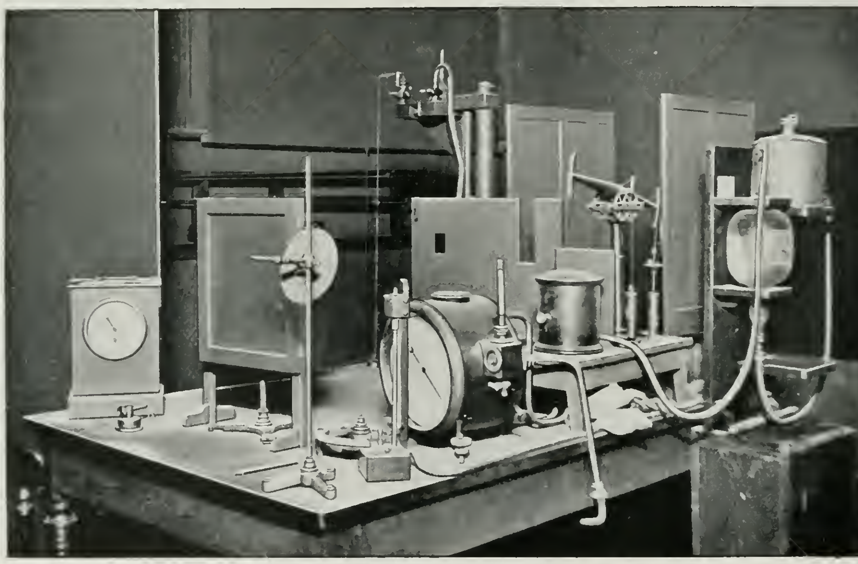

FIG. 8.—A PENTANE PHOTOMETER.
Pentane vapour is now commonly used in these tests instead of candles.

These coloured fringes, running close and parallel to the edge of the shadow when a point of light is used, arise from what is known as the diffraction or inflection of light. Light is propagated by ether waves, and these waves, when passing round the corners or edges of opaque

bodies, interfere with each other, and produce by their accordance and discordance the blue, yellow, and red fringes we are speaking of.

what cannot so well be represented in a sectional diagram, that the shadow of the earth is a cone of darkness, *u*; and, further, that if a screen of immense size

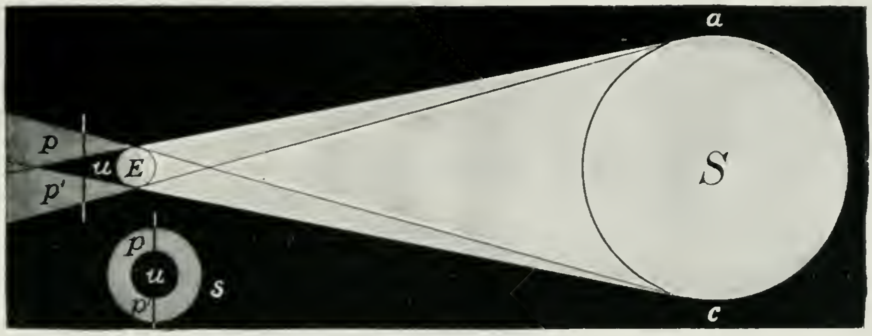

FIG. 9.—HOW A PLANETARY PENUMBRA IS FORMED.

S, sun; u, a cone of darkness (the umbra) cast by the earth, E; p p', penumbra: the shadow of a shadow.

could be placed at *p p'* to receive the earth's shadow, we should have, as at *s*, a central dark circle surrounded by a ring of penumbra. The only screen that ever shows us this darkness is the moon, and at such times it is eclipsed.

The production of a penumbra is easier still to understand, and may be thus explained:—In the experiment illustrated by Fig. 6 bring the lights *a* and *c* nearer to each other, until their shadows overlap. There is now a middle space of darkness, the *umbra*, *u* (Fig. 10), and on either side of it, shadow less complete, the *penumbra* *p p'*. The light from neither candle reaches *u*, whereas the penumbra is illuminated by one or other of the candles.

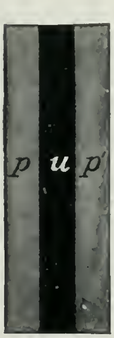

FIG. 10.—FORMATION OF A PENUMBRA.

u, umbra: p p, penumbra.

The penumbra which surrounds a planetary shadow is of exactly the same nature as the foregoing, and is produced in the same way (Fig. 9). For if S represents the surface of the sun, and E the earth, it is evident that the rays emanating from *a*, and those emanating from *c*, shine upon E in a precisely similar manner to the rays falling on *b* from *a* and *c* (Fig. 6), and a dark shadow, *u*, is formed along with a penumbra, *p p'*. The surface of the sun, however, is a collection of luminous points like *a* and *c*, and it will readily be perceived,

From our survey so far we have learnt the simple lesson that, wherever light can reach, there shadow can be produced—on the grand scale when the light obstructor happens to be a planet, and on the comparatively minute scale when hand-shadows are cast on a wall. This survey, however, cannot be said to be as yet complete, for there are what one might term (anomalous though it may seem) *hidden shadows*, which require other than human eyes to see them. Nothing better illustrates the finite nature of our knowledge. There are rays which the eye cannot perceive, and therefore there are shadows of which we are insensible. With the Crookes tube and a photographic plate we have been made cognisant of the existence of shadows obtained with Röntgen or X-rays which otherwise would have been for all practical purposes unknown to us.* These are molecular or atomic

* CASSELL'S POPULAR SCIENCE, Vol. I., p. 73.

shadows of such importance that a word or two concerning them will be a fitting complement to what has already appeared in POPULAR SCIENCE on this fascinating subject.

The words shadowgraph and skiagraph (Gr. *skia*, "a shadow") sometimes applied to the pictures obtained on sensitive plates by means of X-rays sufficiently

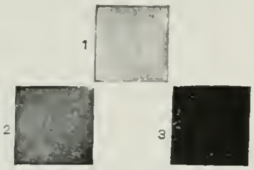

FIG. II.—RADIOGRAPHS OF OXIDES.

1, magnesium oxide; 2, zinc oxide; 3, mercuric oxide.

indicate the idea that these pictures are in some measure shadows. It remains a curious fact, however, that while some substances produce this kind of shadow, others do not unless the X-rays pass through a considerable thickness of them. What is the collateral attribute of these bodies which will enable the reader to say which is permeable and which impermeable?

At first it was thought that it was a question of relative density, for heavy bodies, like platinum and lead, give dense X-ray shadows, while lighter substances, like the metals aluminium and magnesium, are comparatively shadowless or transparent. Röntgen was careful to point out, however, that density or comparative heaviness alone cannot determine this shadow-producing power, because it is possessed in varying degree by many substances chemically different but alike in density. Early in the year 1896 it occurred to me, from the study of certain analogies, that shadow-producing power was dependent upon atomic weight, and upon experimenting with my friend, Mr. H. B. Knowles, such was found to be the case. As the point is one of considerable interest in the philosophy of X-rays, a little more explanation will be acceptable to those readers who wish to go beyond the mere surface of the question.

In that wonderful classification of the elements which chemists have of late years adopted, which is based on the weights of their ultimate particles, known as atoms—a classification of an importance to rank with Newton's law of gravitation—it is clearly pointed out that there are groups of elements whose properties are comparable. The metals magnesium, zinc, cadmium, and mercury, for example, with atomic weights of 24, 65, 112, and 200 respectively, are a comparable group, and show a gradation of their qualities with ascending atomic weight—no erratic jumping about, but a gradual increase. Just as social importance, regarded as a quality of man, may, in a comparison of several of them, become greater and greater in some communities with the increase of their individual wealth, so here a given quality possessed in a small degree by magnesium may be inherent in each of the other metals in this group to an increasing extent with their increase in atomic weight. This is the case when the metals are compared as X-ray shadow producers. The following figures show that mercury is eleven times more effective in this respect than magnesium :—

Element.	Atomic weight.	Relative transparency to X-rays. Water = 1.
Magnesium	24	0·5
Zinc	65	0·1
Cadmium	112	0·09
Mercury	200	0·044

These elements, which are merely taken as types, are screens to the X-rays of different degrees of penetrability, and the collective atomic shadow is densest where the atomic weight is highest, and lightest where the atomic weight is lowest.

As with the elements, so likewise with their compounds. If we take the com-

pounds of these metals with oxygen—viz. magnesia, zinc white, cadmium oxide, and red precipitate, we observe a gradually increasing power of X-ray shadow producing when the rays are obstructed by the same thickness of powder in each case. Here are the radiographs of three of them (Fig. 11). The other facts of X-ray science are similarly in keeping with these simple statements. Carbon, with one of the lightest of atomic weights, 12, gives practically no shadow; glass, containing lead, atomic weight 207, gives the densest of shadows; and in the hand and arm the light-weighted atoms of nitrogen, oxygen, hydrogen, and carbon constituting flesh, are practically shadowless; while the heavier calcium compounds in bones are by comparison marked X-ray obstructors (Fig. 12).

This, in a few words, is the chemical philosophy of X-ray work, which must now, at the commencement of the twentieth century, be included in any complete account of shadows. Yet only a few years ago X-ray shadows were not even dreamed of. Such is the rapid advance of modern science.

From a radiograph by Mr. Campbell Swinton.

FIG. 12.—THE NEWEST KIND OF SHADOW: RADIOGRAPH OR SHADOWGRAPH OF HAND.

THE WIZARD ELECTRICITY.—IV.

"WIRELESS" TELEGRAPHY.

By R. GORDON BLAINE, M.E., Assoc. M. Inst. C.E., Etc.

(Lecturer at the City Guilds Technical College, Finsbury, London.)

To signal to an ally of our position and movements, to speak with friends in distant lands, or to negotiate some important bargain with a customer beyond the seas, was the dream of fifty years ago—the reality of to-day. It is curious to reflect that until recent years many Oriental—and even some savage—peoples far surpassed us in ability to rapidly communicate messages over long distances without any apparent or visible medium of communication. It was the puzzle of our officers in Afghanistan how the news of our intended movements in the field could be known by our enemies, long distances away, almost as soon as they were determined upon. Natives were offered immense bribes to impart the secret, but money could not buy it, nor could the fear of death extort it, and the secret remains in their possession until this day. It is said that on the same day in which England and civilisation lost that good man Gordon, in Khartoum, the fact was known in the bazaars of Cairo, though there was no telegraph and no railway, the distance being something like 1,100 miles. It may be said that in this case the event was determined upon beforehand, and that in both cases heliography may have been employed to signal an expected result. This, however, is an unlikely explanation, for the strictest watch in Afghanistan failed to detect any such signals. Recently the Kaffirs have shown that they possess, to some extent, this unexplained power of communicating with friends at a distance, and the Matabele have often surprised our officers in the same way. Whatever the explanation of these phenomena may be, they are of speculative interest only to us now, as science has placed surer and more useful, if more expensive, methods at our disposal.

Almost as soon as electrical science began to take definite shape, experimenters were at work on systems of electrical communication; and those early workers, though achieving, perhaps, little success themselves, cleared the way for modern triumphs. In the early researches in this field the earth or water was often used as a conductor, and some inventors at the present day use the same method. If it could only be proved, as one recent patentee asserts, that the earth is a gigantic conductor, of which we have only to avail ourselves in order to transmit electrical impulses to any distance, the matter would be much simplified. But whilst it is true to a certain extent that the earth does act as a conductor of electrical current or disturbances, its conducting power varies very much in different places, and the impulses can only be transmitted in a very erratic and, in some cases, roundabout way.

Passing over the "anticatelephar" of Edwards (1829), in which air or water in pipes seems to have been the medium, we find Mr. Edward Davy in 1838 preparing to send waves or impulses by "the conjoint agency of sound and electricity," to be received in the focus of an electro-magnetic receiver at a distance. Professor Morse in 1842 gave a practical demonstration of the use of an ordinary submarine telegraph between Governor's Island and Castle Garden, a distance of

one mile. The accidental breakage of his wires by a passing vessel caused him to try the experiment of using the water as a conductor, and, by suitably arranging his wires along the banks, he effected his object and telegraphed "wirelessly," as we now somewhat inaccurately put it. One of the earliest and most sagacious workers in this direction was James Bowman Lindsay, of Dundee—a great man, who was prevented by want of means and a sensitive and modest nature from carrying his ideas to practical fruition. Even as early as 1842 he lectured to classes on electrotechnics, including electric lighting; and at a public lecture in the Thistle Hall, Dundee, in 1853, he proved by experiments not only that a submarine telegraph was possible, but that the water itself might be made to convey the electrical impulses necessary to give readable signals.

The invention of the telephone by Graham Bell in 1876 gave a new impetus to research in connection with message transmission, by providing a receiver of extraordinary sensitiveness for minute interrupted or alternating currents. Thus we find Professor Trowbridge, of Harvard, carrying out extensive researches on the propagation of electrical disturbances through the earth and water. When the telephone was inserted in a circuit two points of which were earthed, then if the two points were at different *potentials* (through, say, the insertion of a battery), the telephone gave evidence of currents circulating in the circuit. When a key and interrupter were inserted in the circuit of the battery, the uniform noise or hum heard in the telephone could be cut into long and short periods, giving signals on the Morse code.

Professor Trowbridge also promulgated the view put forward by Lindsay many years earlier, that it might be possible to signal in this way from the United States to Europe. Intercommunication in this way between ships at sea was proposed, and in 1882 Graham Bell tried the experiment with boats on the Potomac River, succeeding in sending messages over a distance of $1\frac{1}{2}$ miles. Professor Dolbear, of Boston,* made some useful suggestions in 1883. He used an induction coil having in its primary circuit a microphone transmitter, with an earthed wire, as before; and he even proposed the use of the modern elevated wire or "aërial," at the transmitting and receiving stations.

Mr. T. A. Edison in 1885 perfected, in conjunction with Messrs. Gilliland Phelps and Willoughby Smith, a method of signalling to and from moving trains, this being probably the first instance of regular communication with a moving object. Communication with moving ships is now quite common, but was not attempted to any considerable extent until Marconi's time.

Again, in 1891, we find Professor Trowbridge proposing the use of another system—the magnetic-induction system, which is based on the laws discovered by Faraday about 1831—viz. that currents are *induced* in a closed circuit by moving magnets near the circuit, or by starting, stopping, or altering the strength of the current in a neighbouring circuit, or, what comes to the same, altering the relative position of the two circuits. Let the latter be called the primary, the former the secondary circuit. Then a momentary *inverse* current is induced in the secondary circuit when the current in the first is approaching, beginning, or increasing in strength, and a momentary *direct* current is induced in the secondary when the current in the primary is receding, ending, or diminishing in strength. These important laws form the basis of almost all modern electrical progress. Many experimenters have worked with one or both methods, or with

* Fahie's "History of Wireless Telegraphy."

combinations of them. Of these workers Sir W. Preece, until recently chief electrical engineer to the Post Office, has been one of the most persistent and successful.

I.—EARTH CONDUCTION SYSTEMS.

Having glanced briefly at the historic aspect of the subject, we come now to describe in detail some of the more important apparatus employed by inventors working on each of these systems. The basis of all conduction *modus operandi* will be readily understood by a glance at Fig. 1, which shows in outline a typical arrangement. A and B are two metal plates sunk in a river; C and D are two similar plates sunk in a similar way. A and B are connected by an insulated wire, C and D being joined in the same way. If a battery be inserted in wire A B so that a current is sent from A to B along the wire, then the return current from B to A does not all take the shortest route from B back to A, but some of it spreads out in different directions, and, if C is not too distant from B, some of the current finds its way into the wire C D, and so back by D to A, making itself manifest by a suitable receiver inserted in the wire C D. This shows the elements of an earth-conduction system of wireless telegraphy, and it will be seen from the sketch why some trials fail to secure communication over anything like the distance hoped for by the inventors of the apparatus. The distance B C cannot be more than a certain number of times that of C D or A B. The most careful and perfect experiments of Sir W. Preece were conducted with wires or base-lines (A B and C D) each about one mile long, the distance between the lines—*i.e.* the distance of signalling—being four to six miles. With a telephone receiver Drs. Rubens and Rathenau in 1894 read signals transmitted for three miles across the open waters of the Wannsee, the base-lines being 550 feet long. This may be taken as the probable limit of water conduction, and earth conduction is probably less favourable to increase of distance.

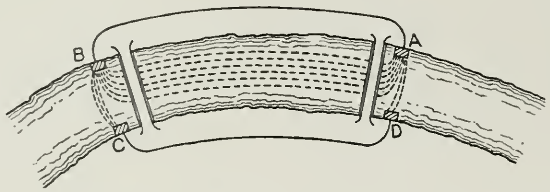

FIG. 1.—THE PRINCIPLE OF EARTH-CONDUCTION.

A and B, C and D, metal plates sunk in a river; A and B are connected by an insulated wire; so, too, are C and D.

For a telegraphic system of this kind the term "wireless" is somewhat of a misnomer; indeed, it is so for any of the modern systems, for they all have wires. Indeed, they all use base-lines, whether horizontal, as in this case, separate insulated coils, as in the induction system, or elevated, vertical, or nearly vertical, "aërials," as in the Hertz-wave systems. But the term "wireless" has come into common use, and simply refers to the fact that the messages are sent without the use of direct metallic connections.

Space does not admit of a description of the circuits and apparatus of more than one or two of the modern inventors under each system. In connection with systems in which earth-conduction is a prominent feature, that of Messrs. Armstrong and Orling has recently attracted some attention. This is the device of a young Swedish electrician, Mr. Axel Orling (inventor of the Orling steering torpedo), with whom is associated a well-known London electrical engineer, Mr. James Tarbotton Armstrong. The transmitting apparatus used by these gentlemen has not, so far as I can find, been fully described, nor can I obtain particulars of it; but the inventors claim that by a make-and-break mechanism they are able to combine with simple earth

conduction currents "high tension discharges which vastly enhance the capabilities of the apparatus." This descrip-

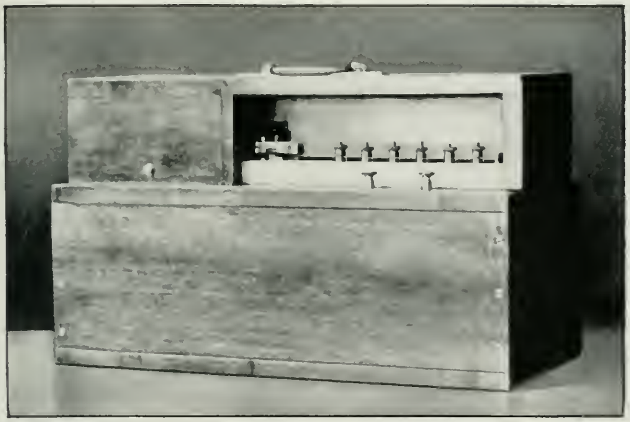

FIG. 2.—THE ORLING TRANSMITTER.

tion points to the use of something of the nature of an induction coil giving interrupted cur.ents at high pressure (usually, but erroneously, styled high tension). The transmitter (*see* Figs. 2, 3, and 4) only requires a few cells giving a pressure of about 8 volts, so that the amount of energy expended is probably small.

In order to send and receive a message, two iron stakes are d'iven into the ground at the transmitter, at a distance of ten feet or more apart, according to the distance of signalling. The receiver is connected with the earth in the same way. The receiver is really the important and novel part of the invention, and experts who have inspected it agree as to its great sensitiveness, and the great ingenuity of design which it exhibits. It is of the nature of an electro-capillary relay, and is shown complete in Fig. 4 and in section in Fig. 5. It is operated by very feeble electric impulses received from a distance, and in turn operates a relay which can be made to work a Morse printer, or other like apparatus. The liquid shown in Fig.   is mercury, the level of the mercury in the chamber, *c*, being maintained in a very ingenious way. A lever, *k*, is delicately poised at a point, *l*, near the delivery end, *h*, of the siphon, *f*. One of the ends of the lever (marked *m*) extends beneath the surface of dilute acid in the chamber, *b*, so that any mercury delivered by the siphon, *f*, may fall upon *m*, and so cause its other end, *n*, to make contact at *o*, and thereby close the relay circuit, *p*, which may in turn operate a Morse instrument.

Both ends of the siphon, it will be seen, are constricted to prevent the mercury from continuing to flow after the electro-capillary force, set up by the current from a distance, has ceased. When the current is received, even if very minute, it sets up this force, which displaces the

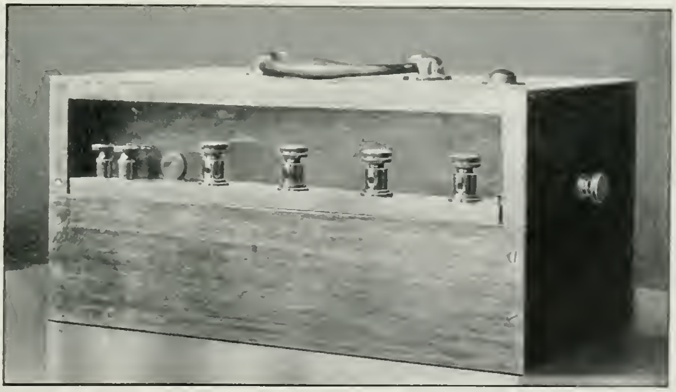

FIG. 3.—THE ORLING TRANSMITTER: ANOTHER VIEW.

liquid from positive to negative, actuating the lever and bringing the relay into action as described. To preserve the level of the mercury, *e*, in chamber, *c*, a reservoir,

r, is provided, which has two tubular legs, *s* and *t*, the former of which extends be-

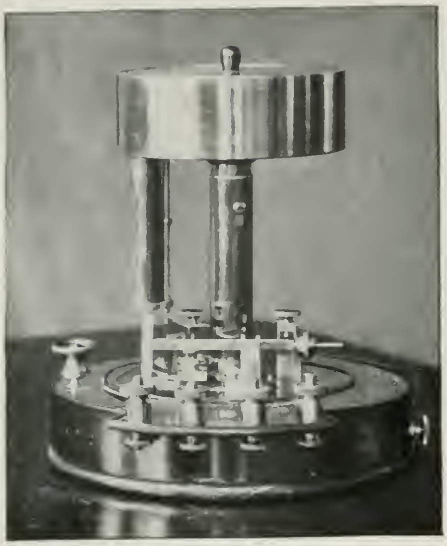

FIG. 4.—TRANSMITTER WITH COVER REMOVED.

neath the surface, where its lower extremity is constricted to prevent too rapid flow; the latter leg is shorter, and terminates with an oblique or V-shaped aperture, *u*, in order that it may gradually open as the level of the liquid falls. The mercury in *r* is retained by the partial vacuum, which is gradually destroyed as air is admitted through *t*, owing to the fall of the mercury in chamber *c*. By this means sufficient mercury is allowed to leave *r* to re-establish the level in *c* and close the vent *t*.

The working of the receiver with a Morse printer is shown in Fig. 5. For long-distance work elevated "aërials" are employed, and a system of relays at given distances apart with telephone receivers (Fig. 6) instead of Morse printers.

Fig. 7 shows the application of the system in a little apparatus designed to prevent collisions at sea. I believe, however, it is assumed that the ships likely to collide with the one carrying the above instrument are supposed to be fitted with corresponding apparatus, which materially diminishes our interest in the apparatus—at least for the present.

Before press representatives and others, demonstrations of the use of these apparatus have been given. Mines have been fired at a distance, a boat has been steered, railway signals have been worked, an unseen party of volunteers communicated with, and some very wonderful things accomplished—only over a short distance, however.

The reasons for expecting only a short distance of transmission in such a case have been referred to; but if the inventors lengthened their base-lines or adapted their apparatus to the Hertz-wave system—and the mention of the use of an aërial seems to foreshadow this—they might greatly increase the distance of signalling. In any case, the

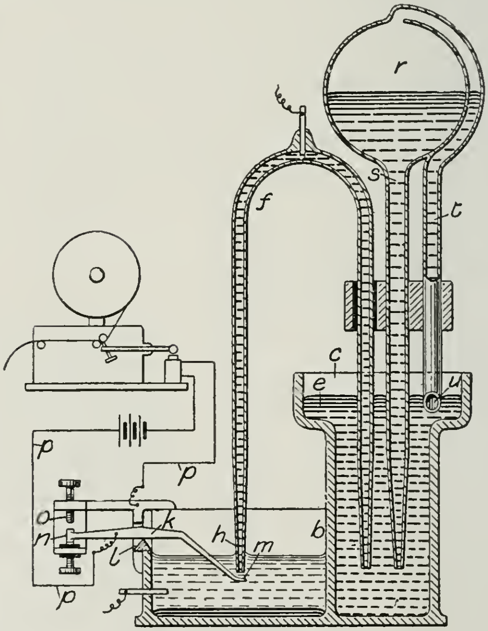

FIG. 5.—RECEIVER WORKING WITH A MORSE PRINTER.

b, chamber filled with dilute acid; c, mercury chamber; e, level of mercury in c; f, siphon; h, delivery end of siphon; k, lever; m and n, ends of k; o, point of contact; p, relay circuit; r, reservoir; s and t, legs of reservoir; u, aperture.

system forms a very interesting modern instance of the use of earth-conduction methods.

Experts are agreed that the weak point

FIG. 6.—TELEPHONE RECEIVER, SOMETIMES USED INSTEAD OF MORSE PRINTER.

of modern "wireless" telegraphy is its imperfectly selective character—*i.e.* messages sent out from one station are received more or less completely by *all* receiving stations within a given distance. The Johnson-Guyott Harmonic system is designed to obviate this difficulty, and to provide a means of sending messages, say, to one vessel only of a squadron. The main portion of the apparatus consists of a Rumkorff coil transmitter, having a disc on which are mounted vibrators or reeds, one of which acts as the armature or contact breaker of the sending coil. The reed disc C is shown in Fig. 8, where E is the speaking reed fitted with a platinum contact, E_1, and E_2 is the tuning reed. The disc can be rotated to bring any required reed into action. The operator at the transmitting station having ascertained the frequency or pitch to be employed, rotates the trembler till the proper reeds are in position. He then turns a screw (Fig. 9, *f*) till it bears on the platinum contact E_1, on the speaking reed, closes his circuit, and turns a tuning screw till the tuning and speaking reeds vibrate in unison. He then proceeds to send his message by means of a key provided for that purpose. The receiving apparatus contains a similar set of reeds, and the electrical impulses received only affect the receiver if their frequency is the same as that of the reed of the receiver.* It will thus be seen that a combination of electrical impulses and sound vibrations is likely to secure the privacy of transmission so much required. This part of the system is very ingenious, but as the earth-conduction method is employed with very short base-lines the distance of transmission in recent trials

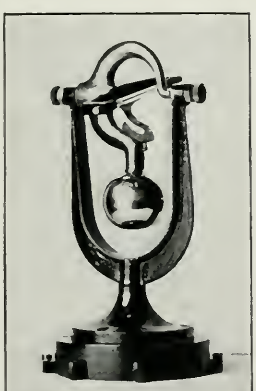

Photo: Messrs. Armstrong & Orme.

FIG. 7.—APPARATUS TO PREVENT COLLISIONS AT SEA.

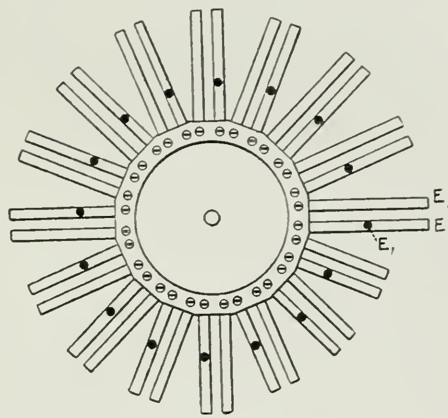

FIG. 8.—REED DISC OF A RUMKORFF COIL TRANSMITTER.

E, "speaking" reed fitted with a platinum contact, E_1; E_2, tuning reed.

* This system is more fully described in the author's little work on "Wireless Telegraphy" now in the press.

on the Thames was not much over 700 yards. The patent, however, mentions the transmission of signals through the

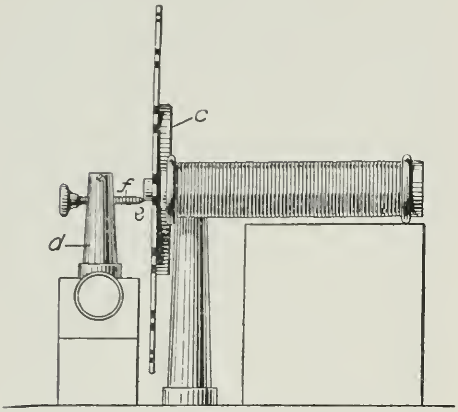

FIG. 9.—VIEW OF A TRANSMITTER.

c, musical trembler; d, contact pillar; e, platinum contact; f, tuning screw of the "speaking" reed.

earth, water, or *air*, so that the system may yet be applied to long-distance work.

II.—INDUCTION SYSTEMS.

The laws of induced currents upon which induction systems of "wireless" telegraphy depend for their success have already been referred to. An elementary induction system consists of two coils or circuits of insulated wire, one with a battery, a dynamo, or other current generator, also a circuit-breaker or interrupter, if the current be not alternating. Such an arrangement is shown diagrammatically in Fig. 10.

The second or receiving circuit, containing a telephone, may be at a considerable distance from the first, and the coils should be parallel. The interrupted or alternating current in the first or transmitting circuit sets up induced currents in the second, which may be heard in the telephone. By a simple arrangement of wires with necessary apparatus and a key, the receiving circuit may be made the transmitter, and *vice versâ*. Sir Oliver Lodge, the Principal of Birmingham University, has been the most persistent and successful experimenter in this field of research. In one case he employed an alternate-current dynamo as his generator, using a coil about a ¼ mile long, enclosing a rectangular area of 150 by 30 square yards. He also used a condenser in each circuit, the condenser being similar in its functions to a Leyden jar, but of greater capacity. A transformer was also employed, a transformer being similar to a Rumkorff coil, in which a thick wire inner or primary coil has a very long, fine, well insulated wire as secondary outer coil wound on the first. An interrupted or alternating current on the primary induces in the secondary a similar current of very much higher electro-motive force or pressure. The frequency of the induced electric impulses was reduced to about 384 per second, and they gave rise to a

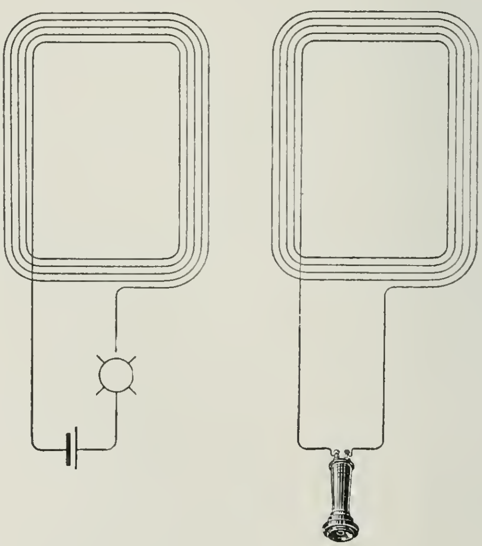

FIG. 10.—AN ELEMENTARY INDUCTION SYSTEM.

This comprises two coils of insulated wire, one with a battery, and a circuit-breaker, if the currents are not alternating.

pleasant note in the telephone. The receiving circuit was tuned as to its frequency, so that it responded best to the frequency employed, but when experiments were performed without due regard to this tuning or "syntony," as it is

technically called, the National Telephone Company's telephones over 100 miles away responded to the transmitter, thus showing the great distances to which induction systems are suited. When the circuits were properly tuned, however, the signals were not audible to outsiders more than two miles away.

These experiments demonstrated the powerful effect of induced currents, but it also showed some of the difficulties encountered in using such a system, for "stray" impulses, both terrestrial and extra-terrestrial, make themselves evident in the telephone in a very persistent and curious way. In connection with this a very important experiment was made some years ago by Sir W. (then Mr.) Preece. He attempted to signal, by induction methods mainly, between England and Ireland. A circuit was made up from Carlisle to Haverfordwest in England, and another from Belfast to Wexford in Ireland. The whole telegraphic system of the country was stopped from midnight to 2 a.m. on one morning in June, 1895. Attempts were made to signal, but it was impossible to distinguish the signals on account of the strange incessant babel of sounds which filled the telephone receiver. The hum of two or three alternate-current electric lighting stations could be clearly distinguished, but the strange medley of weird noises, due in part, it may be, to electrical effects outside the earth, prevented the experiment from being a success so far as message transmission was concerned.

The difficulty is not confined to induction systems. Sir O. Lodge has recently observed,* in experiments where the ordinary inductive influences were inoperative, and where a sensitive telephone receiver was connected to a low resistance circuit, the ends of which dipped into the sea, that certain earth-current disturbances were strongly in evidence. These have been classified into noises like

(*a*) Uniform flowing or rushing water.
(*b*) Intermittent crackling.
(*c*) Bubbling and boiling water.
(*d*) Rocket-like disturbances.
(*e*) High-frequency disturbances, not detectable by the telephone but appreciable by the "coherer."*

The rocket-like disturbances are like a shrill whistle dying away in pitch. They may be due to meteorites, which, rushing through the atmosphere, produce electrical disturbances which diminish in frequency as the velocity of the meteorite increases. They are observed more at night than during the day—not that meteorites are more plentiful at night, but the highly ionized daylight screens the effect from the observer.

These experiments show some of the difficulties to be overcome in successfully using either of the systems referred to. It should be observed, however, that in most of the systems in use we really have, in all probability, a combination of earth-conduction and induction advantages and disadvantages, and that unless very special arrangements are adopted we cannot affirm that the system of any inventor belongs solely to any one class. The apparatus here described are not put forward as being the *best* of that class, but are merely taken as modern examples, illustrating the use of the principles peculiar to that system.

Hertz-wave systems, in which the all-pervading ether is made the vehicle for the transmission of messages, are of greater interest, and have met with greater success. These will be dealt with in another paper, when the wonderful Marconi system will be explained.

* "Proceedings" of the Royal Society, January, 1903.

* This apparatus will be described in a future article.

ORGANS THE HUMAN BODY HAS OUTGROWN.

THE "VERMIFORM APPENDIX" AND THE "THIRD EYE."

By F. W. STANSFIELD, M.D.

HIDDEN away in various parts of the human body are several organs the use of which has long been a mystery. The study of evolution has thrown a flood of light upon these, as upon other questions of natural history, and in some cases at least it is known that they are the degenerated representatives of organs which were of service to our pre-human ancestors, but which to us are of no use at all—sometimes, indeed, harmful; in other words, they are organs which the human body has outgrown, but has not completely discarded.

Perhaps the best known of these—and of particular interest just now because of its connection with the recent illness of his Majesty the King—is the *vermiform appendix* of the *cæcum*, or blind gut. What we are accustomed to speak of as the "bowels" is in reality a single continuous tube, some twenty odd feet in length. The greater part of this tube is of tolerably uniform calibre, and is known as the *small intestine*, while the last five or six feet is of much larger calibre, and is known as the *large intestine* (Figs. 1 and 2). The small intestine does not gradually widen to become the large intestine; but on the contrary, the latter is widest at its commencement, and the small intestine joins it somewhat like a river running into a lake. The entrance of the small into the large intestine is guarded by a valve (the *ileo-cæcal valve*) (Fig. 2), which prevents the regurgitation of the contents of the large into the small intestine. It is this dilated head of the large intestine which is known as the *cæcum*. Just below the opening into it of the small intestine there is another and much smaller opening, which is found to lead into a blind canal from three to six inches in length and about the diameter of a goose-quill. Seen from the outside, this canal appears as a worm-like appendage to the *cæcum*, and is known to anatomists as the *appendix vermiformis* (Fig. 2). The function of this little organ, if such it can be called, is very

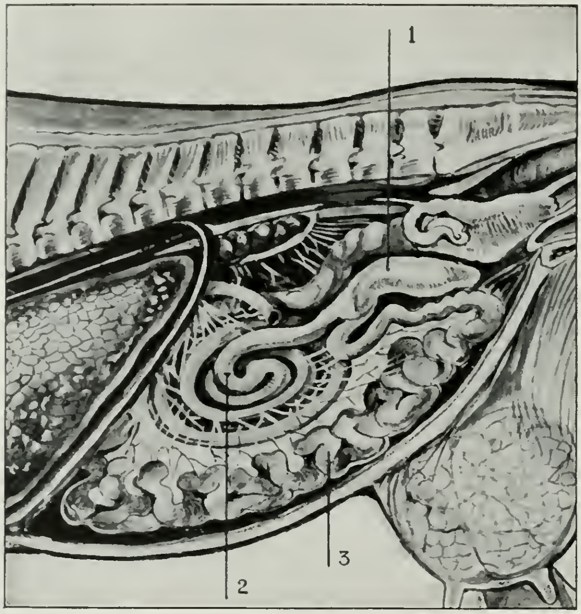

FIG. I.—INTESTINES OF A COW, SHOWING LARGE CÆCUM.
1, Cæcum; 2, large intestine: 3, small intestine.

obscure. It does not serve for absorption, because the contents of the *cæcum* do not normally enter it at all. It has been supposed by some to have a secretory function, but this cannot be of great importance, because the appendage has often been removed in its entirety, not only without any injury to the patient, but with great benefit. Of course, it is not removed except when diseased, but its position in the abdomen renders it particularly dangerous when in that condition. On account of its idle condition, it is also more liable to inflammation than almost any other portion of the intestine. Sometimes it is invaded by parasites (worms, etc.), which breed in it, and occasionally a small seed or other hard body may lodge in it. In either case the "appendix" frequently becomes inflamed, and the inflammation often spreads to the general lining of the abdomen, and so *peritonitis* is set up. This may be localised or general, but in either case the patient's life is in great danger until the offending body is removed, and unless this be speedily done death is too often the result.

Now the question arises, Why do we have in our bodies this small, useless organ, which is so often dangerous to its possessor? The answer is supplied by comparative anatomy. In some animals, especially the herbivorous species, the *cæcum* is relatively a much larger organ than it is in man (compare Figs. 1 and 2), and it is obvious that it performs an important function, although that function is at present but imperfectly understood. It is believed that the vermiform appendix, which is found only in man, in certain of the higher apes, and in the wombat, is the shrunken remains of the *distal* portion of the *cæcum*, as found in other animals which live upon more bulky and less nutritious food. That is to say, that man is the descendant of an animal which lived upon, say, grass and twigs; that as man's ancestors advanced in intelligence they gradually took to more nutritious foods—*e.g.* nuts and small animals—and that the huge *cæcum* of the herbivora, being no longer required, gradually shrank, but did not shrink quite evenly, so that the useless portion, instead of disappearing entirely, remained as the vermiform appendix. Had man remained for a few millions of years longer in the savage state, it is probable that the vermiform appendix would have disappeared altogether through natural selection; but the development of modern surgery is tending to check the action of natural selection by preserving the lives of those who would otherwise die as the result of inflammation in their appendices. Nevertheless, should the human

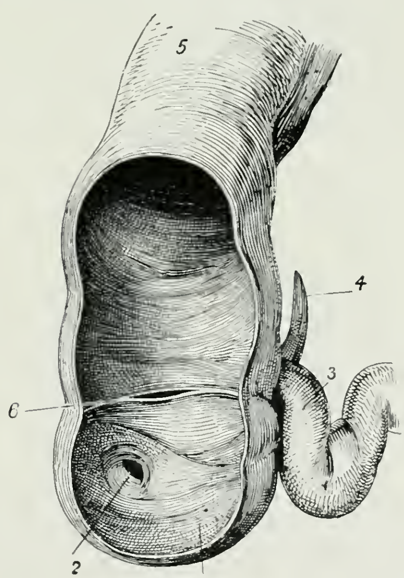

FIG. 2.—SECTION OF THE LARGE INTESTINE IN THE HUMAN BODY, SHOWING OPENING OF VERMIFORM APPENDIX.

1, Cæcum; 2, opening of vermiform appendix; 3, small intestine; 4, vermiform appendix; 5, "colon" or large intestine; 6, ileo-cæcal valve.

race survive long enough, the appendix will still disappear, because surgery does not save all the victims of appendicitis, but only a fortunate few.

Another vestigial structure which has reached a much lower stage of degradation than the vermiform appendix is the *pineal body*, or *pineal gland*, as it was formerly called. This is a little excrescence growing exactly in the middle line from what was once the exterior surface of the brain, but which, in consequence of the brain having become folded upon itself during growth, is now nearly the centre of the general brain mass. For many centuries nothing was known as to the function or significance of this little body. Some curious guesses, however, have been made as to its function. Thus the celebrated French philosopher Descartes supposed that it was the seat of the soul, his reasoning being that since the principal sense organs were paired — a picture, for instance, being formed in each of the two eyes, but only one being perceived by the mind —there must be some central part to which these impressions were transferred. He reasoned further, that, as the "pineal body" was central and not paired like most other parts of the brain, and as no other function was known for it, it was therefore very probably the centre of perception and thought. In the present state of our knowledge, of course, such a theory would not be regarded seriously. One very serious—if not fatal—objection would be that the pineal body is relatively much larger in many low vertebrates—such as the frog (Fig. 10), toad, and some lizards —than in man. Also, that it is relatively very much larger in the half-developed fœtus than in the adult brain. At the time of Descartes, however (seventeenth century), the science of comparative anatomy did not exist, the human species being the only one whose internal anatomy was thought worthy of investigation.

Photo: Cassell & Co., Ltd.

FIG. 4.—THE SMALL-EYED LIZARD (*LACERTA OCELLATA*).

This curious little creature has the eye-like scale, shown in Fig. 3, strongly developed.

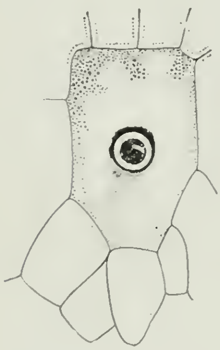

FIG. 3.—SCALE RESEMBLING AN EYE, FOUND ON THE TOP OF THE HEAD IN SOME LIZARDS. *(See also Fig. 4.)*

This particular scale represents that found in Calotes ophiomaca.

When we come to examine the pineal body in other animals than man, we find that it exists practically all through the vertebrates—*i.e.* in mammals, birds, reptiles, amphibia, and fishes. In none, however, does it appear to perform any function, and up to the year 1886 its significance was a complete mystery. It was found, however, that the organ—if such it can be called—was relatively smaller in man than in almost any other animal, and that in other animals, as in man, it was relatively larger in the immature than in the adult state. It had been known for many years that in many animals of the lizard class there existed, on the top of the head and in

the middle line, slightly behind the level of the two eyes, a scale of armour which was readily distinguishable from the other scales. In some cases this scale has a curious resemblance to an eye (Fig. 3), especially in one species, which, oddly enough, has received the name of *Lacerta ocellata*, the small-eyed lizard (Fig. 4), not so much on account of this one spot, but because its whole body is dotted with eye-like spots, which, however, are no more eyes than are the eye-like spots on the tail of the peacock or those upon the wings of the "eyed" hawk-moth. No suspicion seems to have been raised that the eye-like spot upon the head was any more an eye than the rest of the spots. Ahlborn, in 1883, published an account of the development of the pineal body in the lamprey, and seems to have been struck by the similarity of its development to that of an eye. In 1886 De Graaf, another German, examined and described the development of the *epiphysis* (*i.e.* the pineal body) in certain amphibia and reptiles, and, in the case of the "blind-worm" (Fig. 5) he observed that the *epiphysis* grew up to the surface of the head, that a certain portion passed through an opening in the skull and was there cut off and left lying under the skin, the skull again closing up. He seems to have recognised the resemblance in this process to the development of an eye, but not to have recognised the cut off portion as being actually an eye.

At this point the work was taken up by Baldwin Spencer, an Oxford man, who carefully and systematically examined the pineal body and its extensions in some twenty-nine different animals of the lizard tribe, and his work let in a whole flood of light upon a previously obscure subject. Spencer found that the pineal body in certain lizards was connected by a nervous strand or stalk with an organ (previously supposed to be a gland) which lay just under the skin on the top of the head. Of course, there had to be an opening in the skull for this connection, and this opening is the *parietal foramen*, which does not exist in adult birds or mammals, nor is it found in many reptiles, but only in a few—mostly lizards. It is very conspicuous in the skulls of certain extinct animals, viz. the *Labyrinthodonta*, which are considered to be the ancient representatives of living amphibia.

FIG. 5.—THE BLIND-WORM *(ANGUIS FRAGILIS)*.
This lizard is not blind, neither is it a worm. It has two good seeing eyes, and in addition a third, which is blind.

I have previously alluded to the modified scale on the heads of some lizards, which has a singular resemblance—in some cases, at least—to the external part of an eye. Well, an organ was found just under this modified scale, which really *is* an eye, both in general form and micro-

scopical structure. It exhibits all the important parts of an eye—*i.e.* lens, *posterior* or *dark chamber*, and a *retina*, the "retina" in some cases even retaining the microscopical *rods and cones* which are so characteristic of the structure of the human retina. Curiously enough, however, in no case of the whole series is the eye functional, although in several species it comes rather near being so. There is always some imperfection or degeneration which prevents the animal from seeing with this ancient and long-descended eye.

We may take the following parts as necessary for a functional vertebrate eye, (Fig. 6), enumerating from without inwards :—

(1) A *cornea*, or transparent outward part, through which light is admitted to the eye.

(2) A *refracting lens*, by which the rays of light are brought to a focus.

(3) A *retina*, or sensitive field, upon which the picture is received.

(4) A *nervous connection*, by which the image upon the retina (or rather knowledge of that image) is conveyed to the brain.

Should any one of these parts be lacking, no matter how perfect the rest may be, the eye as an eye is perfectly useless. We are familiar in the human subject with blindness brought about by failure through injury or disease of each of these parts. For instance :—

(1) The *cornea* may be rendered opaque by small-pox, or burns, or inflammation.

(2) The *lens* may be made opaque by cataract, or become useless through displacement or alteration of form.

(3) The *retina* may be rendered insensitive or destroyed by disease.

(4) The picture may be perfect upon the retina, but may fail to be conveyed to the brain in consequence of disease or injury to the *optic nerve*.

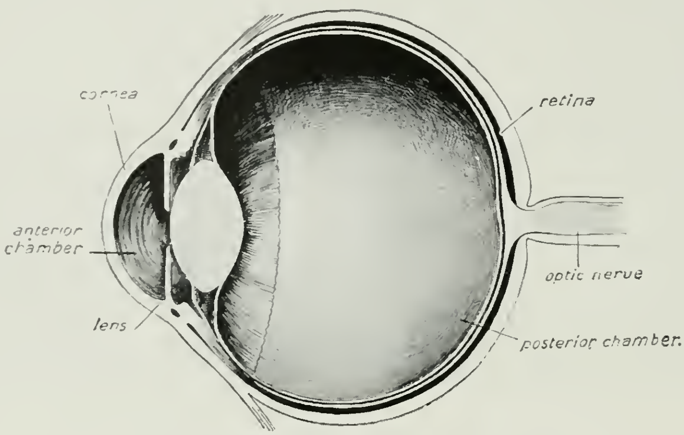

FIG. 6.—DIAGRAM SHOWING STRUCTURE OF A HUMAN EYE.

The following are a few of the animals examined by Spencer, with brief reference to the condition of the four essentials in each. It will be seen that they all fail in some important respect to perform the function of vision, while many are lacking in several of the essential parts. In most cases they fail by having no transparent "cornea"—*i.e.* the eye is buried under opaque skin or connective tissue. In many cases the "retina" has degenerated into pigment ; in others the "lens" is opaque ; and in some, again, the eye is cut off from the brain by degeneration of the "nervous stalk."

In *Hatteria punctata*—a large New Zealand lizard—the eye itself is highly

developed, having, perhaps, the most nearly perfect retina of the series. There is also a more or less transparent lens and an optic nerve, but the eye is buried beneath a thick layer of skin and connective tissue; there is very little ex-pigment in the lens (a sort of cataract, in fact), which prevents the light from gaining access to the retina. The retina also shows signs of degeneration, although the rods are fairly developed. This animal might possibly be able to see to some

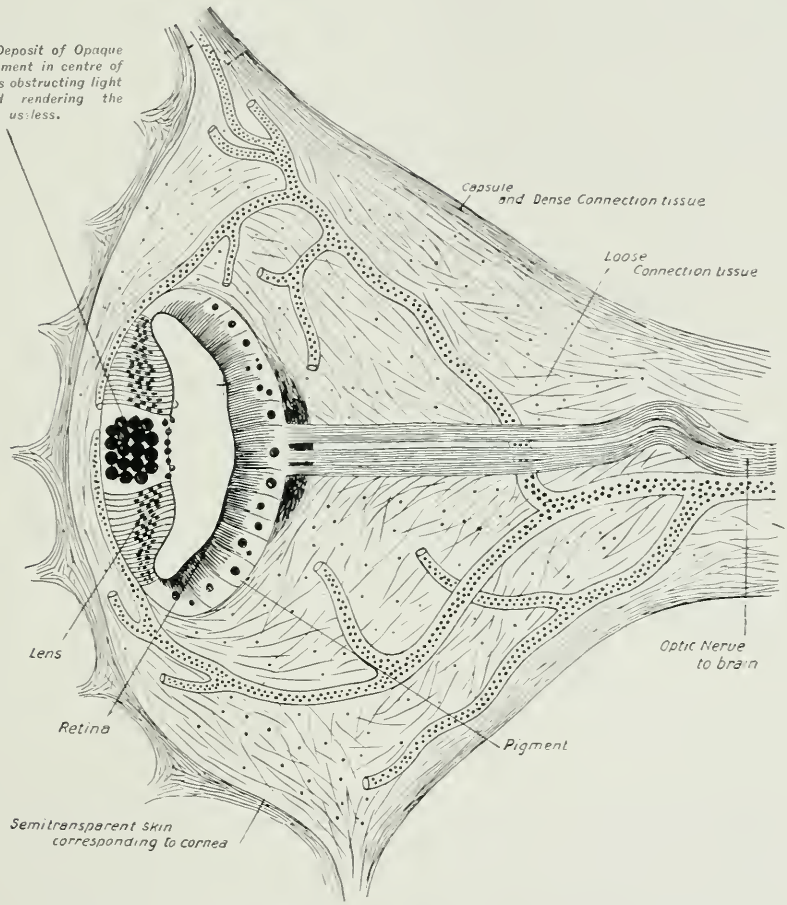

FIG. 7.—THE POSITION OF THE PINEAL EYE IN *VARANUS GIGANTEUS*.
(Longitudinal section.)
Note the opaque pigment which renders the eye useless for seeing purposes even when it is near to the surface of the head.

ternal trace of an eye—indeed, none in the adult.

In *Varanus giganteus*—another lizard, six feet long—even in the adult animal there is a modified scale on the head which strongly resembles an eye, and *through* this a dark spot can be perceived (Figs. 7 and 8). This dark spot on examination turns out to be a deposit of extent with his pineal eye if it were not for the opacity in the lens. If he were to consult a surgeon and have the lens removed, and wear a suitable eyeglass, the defect in his (pineal) vision might be ameliorated. As, however, he has two other very serviceable eyes, which are free from the defects of the pineal, he does not trouble himself about oculists or

spectacle makers. He has outgrown his third eye.

In the chameleon (Fig. 9) there is a more or less transparent cornea, but the lens and retina are in a very imperfect condition and quite incapable of function.

In *Calotes ophiomaca* there is a clearly modified external scale (Fig. 3), which is said to present precisely the appearance of an eye. The eye itself, however, has lost its globular form, and although the lens and retina are both distinguishable, they are obviously functionless.

In our native "blind-worm" (so called, although it is not blind and not a worm, nor even a snake, but really a lizard) there is no external appearance of an eye. If, however, the skin be removed from the head and held up to the light in a fresh state, it is seen that the skin over the *parietal foramen* is free from pigment and semi-transparent, while the rest of the skin is deeply pigmented. The eye itself is small, flattened, and ill-developed, but is clearly recognisable under the microscope as an eye. It is not connected with the brain, but the termination of the *epiphysis* lies close to it. The "blind-worm," therefore, has one blind eye in addition to his two seeing ones.

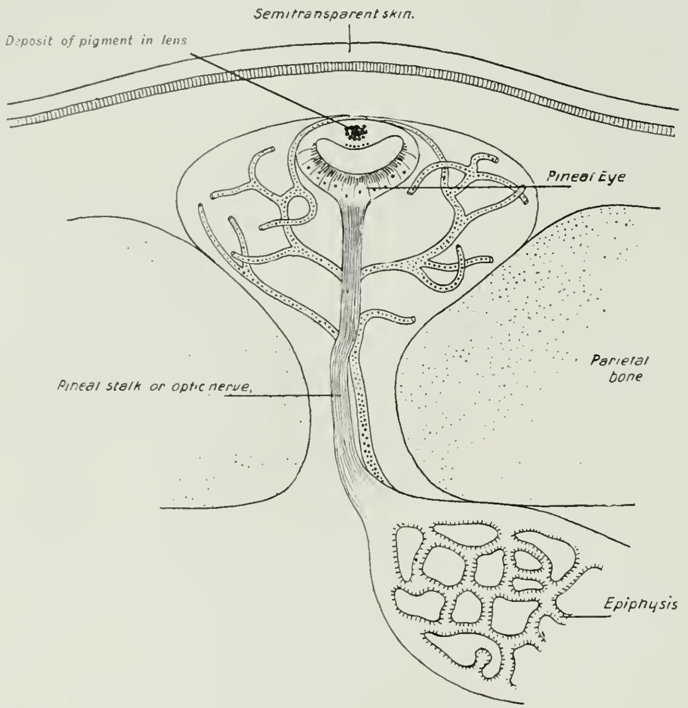

FIG. 8.—THE "THIRD EYE" (*VARANUS GIGANTEUS*), SHOWING RELATION TO BONES OF SKULL.

Looking the matter over, then, what is the meaning of the pineal body and its connection in a few lizards with an extinguished eye? From the point of view of evolution the answer is perfectly clear. It is that mammals (including man), birds, reptiles, and fishes are descended from a common ancestor who had an eye on the top of his head, or, at all events, in the middle line of what was going to be (in the evolutionary sense) his head. Man is the species which has got furthest away from this common ancestor—who has changed most during the ages. It is possible that there may be still existing

some exceedingly conservative descendant of this pre-Adamite ancestor still clinging more or less to his ancient form and mode of life. There is some reason to suppose that we may find this far-away relation among the *Ascidians* (otherwise known as "sea-squirts," or "sea-cucumbers"). The adult sea-cucumber, as its name implies, has more resemblance to a vegetable than to an animal. There are many species and several genera. Some of them grow in colonies like polypes. They all fix themselves to rocks, like plants, and stick there. In the adult state they have no eyes at all. The larval or immature ascidian, however, is quite a different creature. He is like a small fish with a rudimentary tail, and swims freely in the sea. He has a trace of a *notochord* (which is the cartilaginous first appearance of a spinal column in the fœtal human being, dog, bird, frog, and fish). Most significant of all from our present point of view, he has a single eye in the middle line of his head exactly on the same plan as the degenerate pineal eye of our lizards. Here then, perhaps, is the modern and comparatively little-changed representative of one of our ancestors. He is a living illustration of the virtue of contentment and its results. Living at the bottom of the sea, his circumstances have changed but little during the ages, and he has not found it necessary to acquire new eyes, hands, feet, brain, ears, lungs, and the other things which we think absolutely essential. Not only was he content with the things which were good enough for his fathers, but he was even content to do without some of them.

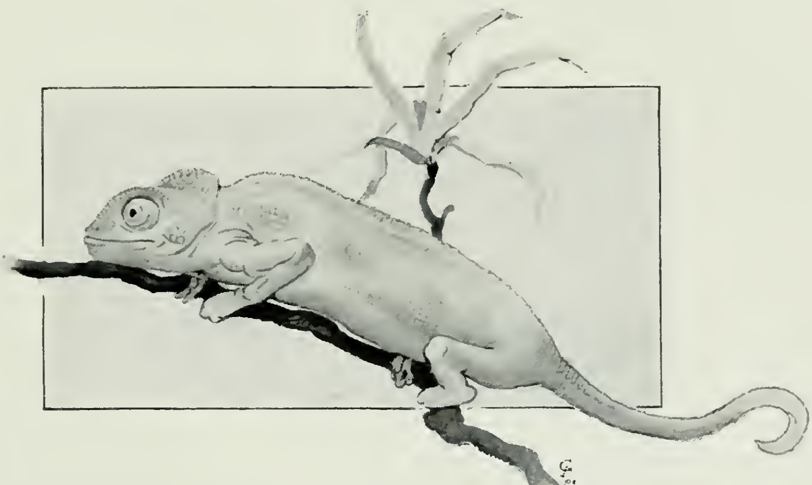

FIG. 9.—THE CHAMELEON.

The "third eye" of the chameleon is much more reduced than it is in Varanus, but it can still be easily detected.

Fixing himself to a rock and opening his mouth, he found that food came to him without his seeking; so, no doubt, he said, "What is the use of a tail to me? I don't want to go roaming about the sea to be snapped up by some hungry beast. I shall just stick here where I am comfortable." And so he did, and in time his tail, from want of use, withered away. Not only that, but he found he could get on without opening his one eye, and so in time he lost that also. Fortunately for us pedigree hunters, however, the force of heredity was strong enough to reproduce in the young of each generation the tail and eye which their

ancestors formerly possessed, otherwise we should have been quite unable to recognise our relations the sea-cucumbers.

It is this same force of heredity which reproduces in each generation of human beings the gill-slits of our fish ancestors, though these close up before birth, except in a few abnormal instances. The same force also reproduces in all of us the trace of the pineal eye, which was useful to our ancestors millions and millions of years ago, but which we no longer require. On any other hypothesis than the evolutionary the pineal body in man, horse, dog, bird, and frog must remain wholly inexplicable, and a still greater puzzle is the extinguished and useless eye in the various lizards unearthed by the genius of Baldwin Spencer. Spencer's work is, indeed, an irresistible confirmation —if any such were needed—of the ancient evolutionary generalisation which found its modern and greatest exponent in our countryman Charles Darwin.

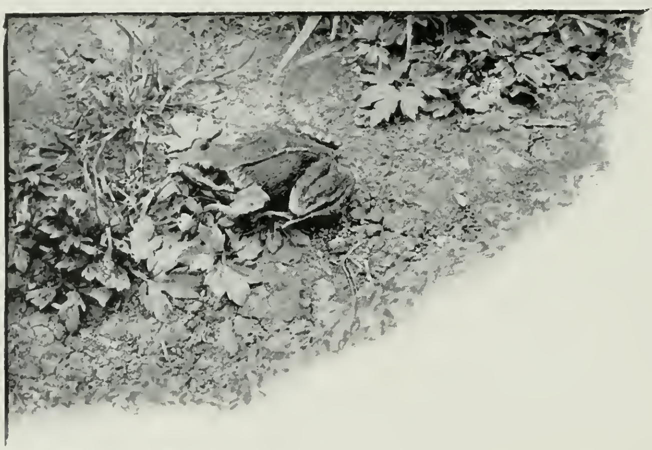

Photo: R. Kearton.

FIG. 10.—THE FROG.

The pineal body is much larger, relatively, in the frog than it is in man, showing that the frog is much more closely related than man to extinct animals which made use of the pineal eye.

THE PLANET MERCURY.

OF all the known planetary members of the solar system, Mercury is the nearest to the Sun, and there is considerable difficulty in observing him in consequence. He is always more or less immersed in the solar rays, and his dimensions are extremely small, so that circumstances combine to render him a somewhat unattractive object, and one seldom coming within the reach of casual observers in such comparatively high latitudes as the British Isles. Some twenty years ago, an astronomer, himself unsurpassed as an observer of this planet, tried to reproduce in imagination the circumstances under which Mercury was first seen. He wrote :—

"The discovery of so small a planet, and one in connection with which the conditions are so directly opposed to successful observation, reflects much credit upon the ancient astronomers, who, after they had detected Venus, Jupiter, Mars, and Saturn, must have had no small trouble in distinguishing Mercury. But no ancient records exist as to the facts of the discovery, so that we cannot form any idea how long this planet eluded detection, or whether it was found simultaneously with the brighter planets of the series. Even the name of the discoverer has not been preserved. Venus and Jupiter would be certain, in the most primitive ages, to attract immediate notice as stars of special type. Their surpassing brilliancy and proper motion in the heavens would cause them to be singled out as of distinct character to the host of stars presented in the firmament. Mars and Saturn must also have been noticed as bodies of similar nature, after which the nocturnal sky was probably scanned in vain for new orbs during many ensuing years. No other bodies belonging to the class of 'wandering stars' could be found, though the relative positions of most of the visible stars were roughly noted, and afterwards compared, with the idea of finding another of these singular objects. Amongst the multitude of stars, in their unique and infinite variety of grouping, only four bodies could at first be distinguished which, by their motions and conspicuous aspect, were proved to be of exceptional character.

"But now a new system of observation may have been introduced, for it has been proved unavailing to search for new planets after darkness has fully set in, though this was naturally suggested as the time best adapted to the work. It was noticed that Venus never departed very far from the Sun, and that, in fact, she was his constant attendant, allowed to recede away from him for a certain distance and then to rapidly approach him again. If, therefore, another planet existed whose motions were controlled similarly to those of Venus, such a planet would, if never travelling far from the Sun, be best discerned in the morning or evening twilight above the place where the Sun made his first or last appearance. An acute observer, reasoning thus, stations himself on a commanding position, whence he may obtain an uninterrupted view of the horizon, and here he begins a systematic search for new planets. Before sunrise he is there looking eastwards, and marking down the positions of the chief stars visible at low altitudes. After sunset his gaze is directed westwards, and the same method adopted. For a long time the process is repeated. Not a single opportunity is neglected. Whenever the sky is clear and the twilight

showing, the observer stands with unfailing persistency at his post. Though for a time the search is fruitless, yet the feeling of expectation and possible success encourages him to renewed effort, and he determines not to relinquish the task he has imposed upon himself until fully persuaded that it cannot yield the coveted prize.

"One night he returns to his work with a sense of despondency, and a conviction that it is hopeless. The sky is remarkably clear as he begins, in his accustomed way, to note what stars are perceptible upon the horizon. Suddenly his eye catches a glimpse of an object which he feels certain could not have been visible on the few preceding nights. His enthusiasm is fully aroused. There is no fixed star in the position he has assigned to the new object, and he awaits—how impatiently and anxiously no one can tell—for the next fine evening to verify his discovery. The intervening hours are counted, every passing cloud is watched, and, ultimately, as the sun falls to the horizon, our observer takes up his place at a much earlier hour than usual. How the Sun seems to lag that night before his setting! How slowly the sky begins to darken after his last rays have disappeared! The observer's eye is eagerly directed towards the point in which the strange star of the previous night was situated, and there, a little to the westward, it is seen again, and with greater plainness than before. Every doubt is now dispelled. This is the object for which he has been waiting so long. His oft-repeated vigils have been rewarded by the detection of another orb belonging to the order of 'wandering stars.'"

FIG. I.—SHOWING THE SIZE OF MERCURY RELATIVE TO THE OTHER PRINCIPAL PLANETS.

But, in thus reasoning, this writer was speaking as an observer of the nineteenth century, with nearly a hundred years of major and minor planetary discoveries behind him, and with his whole attitude of thought influenced by the fact of such discoveries. But the early inhabitants of the Euphratean valley, who first seemed to have practised the systematic observance of the heavenly bodies, differed no less in their habits of thought than in their atmospheric conditions from the Northern European of to-day. With a clearer horizon and more elementary equipment than is now possessed at Greenwich, the Euphratean astronomer observed the *heliacal* risings and settings of the stars and heavenly bodies rather than their culminations, or when they were high in the sky. The "heliacal rising," or the observation of the first appearance of a heavenly body in the eastern twilight before sunrise, and the "heliacal setting," or its last appearance in the western

twilight of the evening before it sets, were observations that brought into especial prominence bodies like Mercury and Venus, which wait closely at all times on the Sun. So far, then, from Mercury being apparently the least and the last "discovered" of the wandering stars of heaven, we find that he is given a place of honour among the "seven planets" of the ancient Assyriological records. He is called *Sulpa-uddu*, which M. Oppert happily renders as the "messenger of the rising sun," and *Ris-risal*, or the "chief of the beginning," and he shares with Venus the title of *Nabu*, the "proclaimer," as precursors of the Sun. Indeed, in 1874 Dr. Sayce stated in the "Transactions" of the Society of Biblical Archæology that the "seven planets" of the Assyrian were always given in the order: Moon, Sun, Mercury, Venus, Saturn, Jupiter, Mars; and though this statement does not seem to have been since either refuted or confirmed, we may take it that, in general at least, the planet Mercury was held to rank in importance even next to the Moon and Sun. With changed conditions of observations, Mercury has fallen from his high estate. In low latitudes, near the equator, where the skies are clear even down to the horizon, and where the morning and evening twilights are of short duration, he is still a brilliant and conspicuous object at times; but in the northern islands of Great Britain, where King Coal has dimmed and darkened the horizon, and turned the night into day by his light, he has become a difficult object, seen only of those who look persistently and with knowledge for him.

Compared with Jupiter and Saturn, Mercury is a most diminutive orb, as shown in the diagram (Fig. 1).

He is situated at a mean distance from the Sun of about thirty-five millions of miles, and completes a revolution in eighty-eight days. His apparent diameter varies considerably, according to position. When the planet is nearest to the Earth, at inferior conjunction, the disc may subtend an angle of 13 seconds of arc; but at superior conjunction this amounts to no more than $4\frac{1}{2}$ seconds. When Mercury is situated at that point of its orbit apparently most distant from the Sun, he is said to reach his greatest elongation, and at such a time is occasionally visible as a morning or evening star, according as his position is west or east of the Sun. But even under the most favourable conditions he is not above the horizon for a longer period than about two hours in the absence of the Sun, and the distance separating the two bodies never exceeds 29°.

This planet has, therefore, received very little attention from observers. His small proportions and constant proximity to the Sun render him a very uninteresting object; hence he is seldom examined in powerful telescopes, so that we have little evidence as to what special features are presented on his disc. It is, however, questionable whether any such details could be distinguished even were the perfected appliances of modern times directed to such a purpose. The smallness of the object and the constant "glare" attending it must obviously prevent good definition, and entirely obliterate any faint markings on the disc, so that we cannot wonder at the negative results which have hitherto attended such observations. Even in the case of Venus—which is a much larger planet and far better situated than Mercury—the results are of very meagre and conflicting character.

Both Mercury and Venus exhibit all the phases of the Moon, their orbits being interior to that of the Earth, and it is evident that these phenomena are the natural result of their varying positions relatively to the Earth. The planets all shine by light reflected from the Sun; hence it is obvious that when either

Mercury or Venus occupies that part of its orbit nearly interposed between the Sun and the Earth—called *inferior conjunction*—it will be invisible, or visible only as a

FIG. 2.—MERCURY AS A CRESCENT.
The southern horn sometimes appears to be blunted, and there are protuberances apparent upon the edge.

very narrow crescent, because its illuminated hemisphere is turned away from the Earth. On the other hand, it is equally clear that when these planets are at the opposite points of their orbits—that is to say, nearly behind the Sun, called *superior conjunction*—they will exhibit discs of circular form, inasmuch as the same hemisphere, and that illuminated, is presented to the Sun and Earth. But in the latter case it is obvious that the apparent dimensions of these planets will be far less than when viewed as a crescent at inferior conjunction. In fact, their distance from the earth is greater by the diameter of their orbits, and this, in the case of Mercury, amounts to about 70,000,000 miles, and has the effect of diminishing the planet's apparent dimensions from 13 seconds to 4½ seconds as it traverses its path from inferior to superior conjunction. When situated about midway between these points, and nearest its greatest apparent elongation from the Sun, it appears like the Moon in her first or last quarters, and is visible either as an evening or morning star.

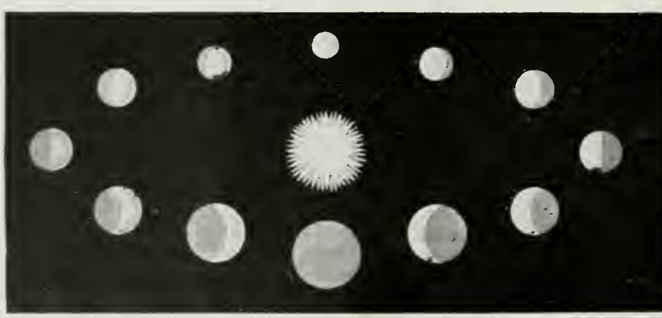

FIG. 3.—AN INFERIOR PLANET IN ITS ORBIT ROUND THE SUN.

Results of observation have occasionally shown that the proportion of the enlightened hemisphere is less than that computed. Schröter, who paid marked attention both to Mercury and Venus, was the first to remark this, and his observations were subsequently confirmed by Beer and Mädler, who attempted to explain it on the theory of a dense atmosphere enfeebling the light at the terminator.

Fig. 3 shows the varying size and phase of an inferior planet in several positions of its orbit.

It occasionally happens that at inferior conjunction the planet is situated precisely between the Sun and Earth, and is then projected as a circular dark spot upon the Sun. This phenomenon is termed a transit, and is sometimes witnessed with considerable interest. Gassendi, at Paris, appears to have been the first to observe an occurrence of this kind — namely, on November 7th, 1631; and since his time they have been commonly observed whenever the circumstances were favourable. The duration averages about 4 hours, though a transit may extend over 7 hours 18 minutes, as on May 7th, 1799, or be visible only for 1 hour 14 minutes, as on November 12th, 1782. The following is

a complete list of the transits of Mercury during the past and present centuries :—

Transits of Nineteenth Century.	Transits of Twentieth Century
1802. November 9th.	1907. November 12th.
1815. November 12th.	1914. November 6th.
1822. November 5th.	1924. May 7th.
1832. May 5th.	1927. November 8th.
1835. November 7th.	1937. May 10th.
1845. May 8th.	1940. November 12th.
1848. November 9th.	1953. November 13th.
1861. November 12th.	1960. November 6th.
1868. November 5th.	1970. May 9th.
1878. May 6th.	1973. November 9th.
1881. November 8th.	1986. November 12th.
1891. May 9th.	1999. November 14th.
1894. November 10th.	

These transits invariably occur in the months of May or November, for the following reasons. The Sun's apparent annual revolution around the Earth carries him through every point of the ecliptic, and he must therefore necessarily intersect the orbit of Mercury at his ascending and descending nodes. The positions of these are in precisely opposite parts of the ecliptic ; hence the Sun crosses them at six months' intervals—that is, in May and November. In the case of Venus, the months are June and December, and it is only at these special periods that transits can possibly occur.

Transits of Venus, as we have seen, at one time seemed to afford the best means of finding out the distance of the Earth from the Sun Mercury is too near the Sun, and too distant from the Earth, for his transits to be made use of for this purpose ; but they are not, therefore, of no account. In the first half of the nineteenth century Le Verrier discussed the observations of all his transits up to that of 1848. He found a discordance between the observed and the theoretical motions of the perihelion of Mercury's orbit, from which he deduced the existence of a new planet, Vulcan, or at least a ring of asteroidal bodies, whose mass should not be much different from that of Mercury, and whose orbit should lie at a distance from the Sun of rather less than half his mean distance, the planes of the two bodies being nearly coincident. He seems to have overlooked the fact that such a planet must transit the Sun at least twice a year, and might transit it as often as four times, and could certainly not have escaped recognition when so doing during the centuries that the Sun has been under telescopic observation.

FIG. 4.—MERCURY IN TRANSIT ACROSS THE SUN.

His statement, however, immediately produced a pseudo-observation of Vulcan from a Dr. Lescarbault, of Orgères, whose little planet was, however, never seen again by anyone, nor could its existence be made to fit n with theory. In 1881 Professor Simon Newcomb rediscussed the transits of Mercury of Le Verrier, together with those which had taken place in the meantime ; and, whilst finding that the discrepancy between the observed and theoretical motion of Mercury's perihelion was even greater than Le Verrier had supposed, he rejected his supposition of a planet or group of planets between Mercury and the Sun,

and suggested an erroneous value of the mass of Venus as the probable explanation. Still more important, he pointed out that the transits of Mercury might prove a gauge as to whether there was or was not any variation in the time of the Earth's rotation on her axis. Observations of the Moon would seem to furnish the readiest check as to any changes in the rotation period of the Earth, and it has long been known that there are variations in the Moon's motion or which no perturbations by the Ea th or planets have yet been found to give an adequate account. But until the nature of these variations are more fully understood, Mercury, as the next most quickly moving body in the solar system, would supply the best test of the constancy or otherwise of the Earth's rotation; and the transits of Mercury would offer the most exact means for observation.

But Mercury is as perplexing and difficult an object to observe in transit as Venus. Not only does the presence of the "black drop" or ligament harass observers and render their times of contact uncertain by "intolerably" large fractions of a second, but when he is actually projected on the body of the Sun there is an aureola—bright, according to some observers; dark, according to others—round the little disc; and at or near the centre of the disc there is sometimes seen a bright spot, or even two spots, which to some observers appear to shift, whilst to others they remain stationary, and others, again, fail to recognise them at all. Sir William Huggins thus described the aureola and spot in the transit of November 3rd, 1868: "The Sun's edge was a little tremulous from atmospheric agitation, but the solar surface was so well defined that the bright granules of which it was composed could be distinctly seen. The planet appeared as a well-defined, round black spot. Whilst carefully examining the immediate neighbourhood of the spot for the possible detection of a satellite, I perceived that the planet was surrounded with an aureola of light a little brighter than the solar disc. The breadth of the luminous annulus was about one-third of the planet's apparent diameter. The aureola did not fade off at the outer margin, but remained of about the same brightness throughout, with a defined boundary. The aureola was not sensibly coloured, and was only to be distinguished from the solar surface by a very small increase of brilliancy. Almost at the same moment that I first perceived the surrounding annulus of light, I noticed a point of light nearly in the centre of the planet. This spot of light had no sensible diameter with the powers employed, but appeared as a luminous point. These phenomena, the aureola and the spot of light on the planet, were distinctly visible as long as the transit continued."

The aureola has been ascribed to diffraction, to irradiation, to a dense Mercurial atmosphere, and to tremors in our own atmosphere. Whatever be the explanation of either aureola or spot, there seems every reason to believe that they are not objective phenomena. A consideration of the numerous observations, and of the conditions under which the observers saw, seem to suggest that they are both at least partly dependent upon the size of the telescope used, and upon the meteorological conditions at the time of observation, and perhaps also, in addition, upon the eyesight of the observers themselves.

The mass of Mercury is not accurately known, and it is difficult to determine it, since Mercury is too near the Sun to greatly perturb other planets, and has no satellite of his own. Professor Young places his mass probably between one-twentieth and one-fiftieth of that of the Earth. As we do not know the mass accurately, neither can we know the

density; but it is probably a little less than the Earth's. Since Mercury is so much smaller than the Earth, and has no very great density, its atmosphere is

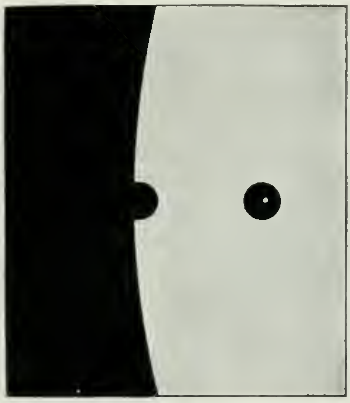

FIG. 5.—MERCURY IN TRANSIT, AS OBSERVED BY SIR WILLIAM HUGGINS, NOVEMBER 8TH, 1865.

probably very rare, and of little amount. According to the theory of Dr. Johnstone Stoney, such a small body would be unable to retain either a gaseous or liquid envelope on its surface, so that from its small mass we might expect that Mercury would possess little more air and water than our own Moon does. Like the Moon, too, Mercury is more brilliant at his limb than at the centre of his disc, indicating a rough and mountainous surface, unsoftened by atmosphere. Still more striking a proof that Mercury possesses no air lies in its small reflective power. On September 28th, 1878, Nasmyth saw Venus and Mercury in the same telescopic field of view, and found that "Venus looked like clean silver, Mercury more like lead and zinc." Now, at this time, as Mr. Proctor pointed out, Venus had a disc about three-quarters full and Mercury about half full. The distance of Mercury from the Sun was only about three-sevenths of that of Venus; so that if the surfaces of both had the same reflective power, Mercury should have appeared between five and six times as bright as Venus. But Venus appeared brighter than Mercury, so that the reflective power of Venus must at the very least be five or six times greater than Mercury's. The brilliancy of Venus is largely due to her dense atmosphere; the reflective power, or *albedo*, of Mercury is no greater than our Moon's or the very darkest sandstone; and we must infer, therefore, that not only has Mercury no atmosphere capable of reflecting light, but that its very crust is formed of sombre materials. This is a point of great importance when we come to consider the markings on its surface and the rotation period deduced from them.

Schröter, at the very end of the eighteenth century, was the first to study the surface markings of Mercury. From the gradual diminution of light on the partially illuminated disc, he concluded that Mercury possessed a dense atmosphere; and when, some years later, the southern horn appeared rounded off on Mercury's crescent, he attributed it to the eclipse of sunlight by a mountain on the planet some eleven miles in height. By timing this recurrence, he got a rotation period for Mercury on its axis of 24 hours 4 minutes. This rounding of the southern horn has been seen again

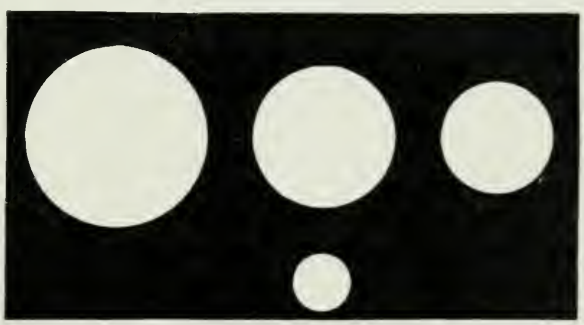

FIG. 6.—COMPARATIVE SIZES OF THE APPARENT DISC OF THE SUN, AT ITS GREATEST, MEAN, AND LEAST DISTANCES, AS SEEN FROM MERCURY, AND FROM THE EARTH.

since Schröter's day by Noble, Burton, Franks, and Denning. The last observer has been one of the most able and diligent students of Mercury's surface, and he depicts a few faint patches or shadings as all that were visible to him in a ten-inch reflector. Other observers, too, have noticed a gradual fading off of Mercury's light towards the "terminator," or

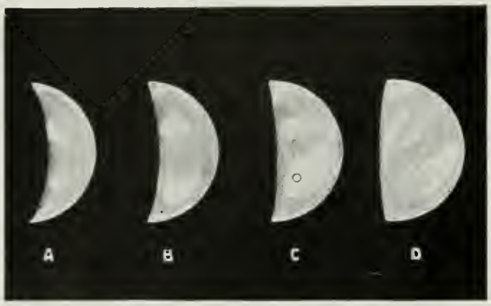

FIG. 7.—MERCURY AS SEEN BY MR. DENNING IN 1882.

A, November 5th; B, November 6th; C, November 8th; D, November 9th.

dividing line between the light and dark hemispheres; and, as has been already shown, many observers since Schröter's time have pointed out that the proportion of the disc enlightened is less than that computed.

After Schiaparelli, the Italian astronomer, had come to the conclusion that from the markings he saw on Venus he could deduce a rotation period of 225 days for her, he turned his attention to Mercury. He found there "markings far better defined than the fleeting shadows on the surface of Venus. . . The spots could be well seen when the planet was only 3° from the Sun, with an apparent diameter of 4″ or 3″. As in the case of Venus, the spots were always found in the same places, even after a lapse of several days. . . . A comparison of all the drawings appears to show that the aspect of the spots is always the same in similar positions of Mercury with regard to the Sun and the Earth, so that the rotation would take place in 88 days, in which time the planet makes one sidereal revolution round the Sun. . . . The spots are chiefly of a streaky appearance, and seem to be of a permanent character; bright spots are occasionally seen, particularly near the regions around the south pole; and this perhaps explains why the latter to Schröter appeared truncated. As the spots are never seen near the limb, the atmosphere would seem to be very dense." The above extracts are taken from the account of Professor Schiaparelli's researches, given by the Council of the Royal Astronomical Society in February, 1891.

As a matter of fact, the markings depicted by Schiaparelli very greatly resemble the "canals" with which he joins up the greater markings on Mars. It will be noted that he seems to see them clearly even when the planet is so deeply immersed in the Sun's rays as to be only 3° away from conjunction—when his disc is but one four-hundredth of that of the Moon to the naked eye. Again, his observations would indicate a dense atmosphere, which we have seen to be in the last degree improbable. In the last few years his observations have been "confirmed" by Mr. Percival Lowell, in so far that Mr. Lowell has published drawings of Mercury of a similar character, though his observations cannot be reconciled with those of Schiaparelli.

The conclusion of the whole matter seems to be that, little as we know of the surface and rotation of Venus, we can know still less of that of Mercury. All the planets that we can study with certainty and ease—the Earth, Mars, Jupiter, and Saturn—all rotate in a short period of hours, not of days. Of Venus we cannot form any conclusion one way or another, the balance of probability, weighed down by spectroscopic observations inclining to the shorter rotation.

By analogy, therefore, we should assume that Mercury, the remaining planet, also rotates in a few hours, not in a period of many days.

Can we, then, form any conclusion as to the state and appearance of Mercury's surface? Mr. Proctor suggested that on Mercury, as on the Moon, there are great smooth tracts, the beds of "seas" (whether it be water or molten lava that formed the primeval ocean we cannot say) composed of dark soil. These "*maria*" on Mercury would account not only for the fact that the breadth of the illuminated part is sometimes less than it theoretically should be, but might also explain the rounding of the southern horn. The southern hemisphere of Mercury appears as a whole less bright than the northern, thus presenting an analogy to the Moon's northern half, where a chain of the great "*maria*" renders it perceptibly darker than the lunar southern hemisphere.

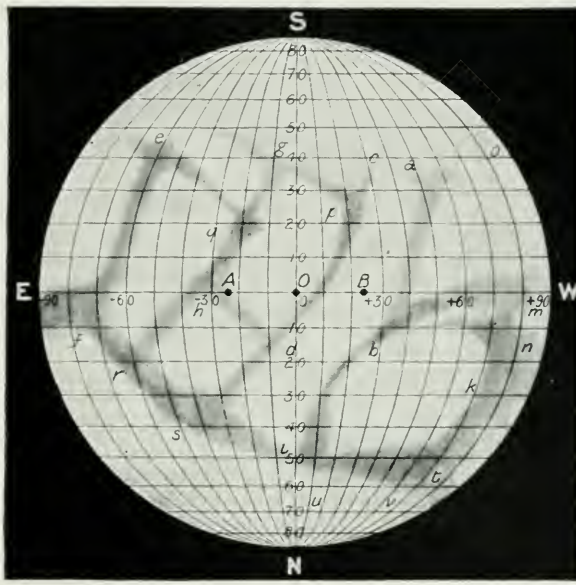

FIG. 8.—MARKINGS ON MERCURY.
As seen by Professor Schiaparelli.

We can thus perhaps picture Mercury as a greater and more sombre Moon, with all the lunar features more pronounced, with greater tracts of grey sea beds, with perhaps greater craters and mountain ranges too. But, whereas to our Moon summer and winter make little difference, for she moves in a nearly circular orbit round the Sun, on Mercury the Sun's rays beat down still more pitilessly and with greater extremes. For Mercury's orbit is very far from being circular; indeed, except for some of the asteroids, he has the most eccentric orbit of all the planets, and the one with the greatest inclination to the ecliptic. The eccentricity of his orbit is so great that his distance from the Sun when furthest is not far short of double what it is when nearest. The light and heat which he receives from the Sun at aphelion* is about four and a half times that received by the Earth; but at perihelion† Mercury receives considerably more than ten times that falling upon the Earth at mean distance. This violent change takes place in the short time of 44 days, the entire period of the revolution of the planet being 88 days. If, therefore, the axis of Mercury is, like that of Jupiter, nearly perpendicular to the plane of its orbit, the planet will still have two strongly marked seasons; but if its axis, like that of the Earth, is inclined at a considerable angle to its orbit, the variations of heat and light which it must pass through in its short year must be most complex.

* "Aphelion"—that point of a planet's or comet's orbit most distant from the Sun.

† "Perihelion"—the point in the orbit nearest the Sun.

A PIECE OF COAL.

TO what precocious intelligence and insight, to what happy instinct of untutored genius, we owe the first discovery of the properties of coal, we may never hope to know; and we can simply add another to the long tale of priceless gifts for which humanity has to thank some unknown and unhonoured benefactor. Chance pieces of stone, picked up from the surface of the ground, do not promise anything beforehand as available fuel; and the early races of men in Europe can hardly have been put to severe straits for firewood amid the unending primeval forests of the prehistoric period. And yet it is probable that the first man who found out that coal would burn slept with his fathers long before the nations of Western Europe had reached the stage of keeping any voluntary record of their actions. Certain it is that the use of coal as fuel originated among the peoples of the cold and inhospitable West, and not in the Eastern cradle of civilisation; and it is also certain that its properties must have been known for a very long time before its use became at all general. The ancient Britons were acquainted with the use of coal, and the Romans, never too proud to learn from the outer barbarian, acquired the precious secret from them. The Anglo-Saxons employed coal to some extent for domestic purposes; but it was not till the thirteenth century that coal mining assumed any importance in England; and the other European nations took to the systematic use of coal as fuel at an even later period, so that in this respect, at least, Britain did not lag. There is a record to the effect that the monks of Newbattle obtained the grant of a coal-pit at Preston, Haddington, between the years 1210 and 1219, but how much use they made of it, or how little, is not quite clear. In the year 1259 Henry III. granted a charter to the freemen of Newcastle-on-Tyne, allowing them to dig coal; but for a long time the new combustible was employed only in the arts and manufactures, and wood continued to be the common domestic fuel. As has been the case with almost every great benefit, the introduction of coal as fuel was stoutly resisted at first, and early in the fourteenth century certain citizens, alarmed at the supposed injurious effects of the burning of coal, prevailed upon Parliament to petition the king (Edward II.) to prohibit its use. The prohibition was granted, but after being in force for a time was withdrawn. Jumping from this infantile period of the coal industry to about the end of the seventeenth century, Great Britain is found to be raising about 10,000,000 tons of coal per annum, much of which was exported to foreign countries. Even then the Britisher was beginning to congratulate himself upon possessing such magnificent stores of potential wealth, and the feeling of satisfaction grew with the years, until with the enormously increased annual consumption there came the haunting dread of speedy exhaustion.

Professor Jevons calculated in 1865 that British coalfields were capable of yielding 83,000,000,000 tons more of the precious fuel, and gave as his opinion, if the then rate of increase in the coal output continued, the year 1970 would see the mines exhausted. This was serious news; and in 1866 a Royal Commission was appointed to examine into the state of the affairs of our kingdom of coal. The report, which appeared in 1871, stated that 90,206,000,000 tons were readily available, and it was estimated that there was a further deep-seated supply of 56,248,000,000 tons, which could be worked in case of need, thus making a grand total of 146,454,000,000

FIG. 1.—HOW THE COAL MEASURES WERE MADE: THE VEGETATION OF THE CARBONIFEROUS ERA.

The principal plants which went to form these mighty forests whose decay and death have given us our invaluable coal deposits were Sigillarias, arborescent ferns, and huge Lycopods and Equisetums, of which only a few degraded representatives remain with us to-day. (Compare with Fig. 4.)

tons. Although the effect produced by these figures is chiefly one of bewilderment at the immense quantities they represent, we can obtain an idea of the time these stores will last by quoting the figures given by experts in 1901, when it was averred that in the 31 years from 1870 to 1901 we had consumed about an eighteenth of our total readily available store, or a quantity of 5,025,000,000 tons. If the figures alone were concerned, it would be easy to fix a date at which no more coal would be forthcoming from British mines—at least, as far as being obtained at a reasonable cost of working is concerned. There are other factors in the case, however. We cannot say definitely that the rate of increase in the consumption will be maintained. A more economical method of using the precious fuel, by which more of its potential energy could be turned into work, would help considerably ; and if a great saving were effected the consumption might, and probably would, decrease materially ; for it is not the fires of the household hearth that are the most ravenous of the black diamond. The countless machines that the ingenuity of man has devised are chiefly to blame—witness the hundreds of tons that are required to drive the engines of a modern battleship or cruiser during a voyage of 2,000 or 3,000 miles. A day's expenditure of coal upon the whole of the railways in the United Kingdom would represent a goodly pile—and there are 365 days in a year. Again, what formidable quantities are daily thrown into the ravening maw of the gas retort in order that the streets of our towns may be lighted and the people warmed and, in a measure, fed — for, though we do not eat gas, at least we eat many a meal that is cooked by it.

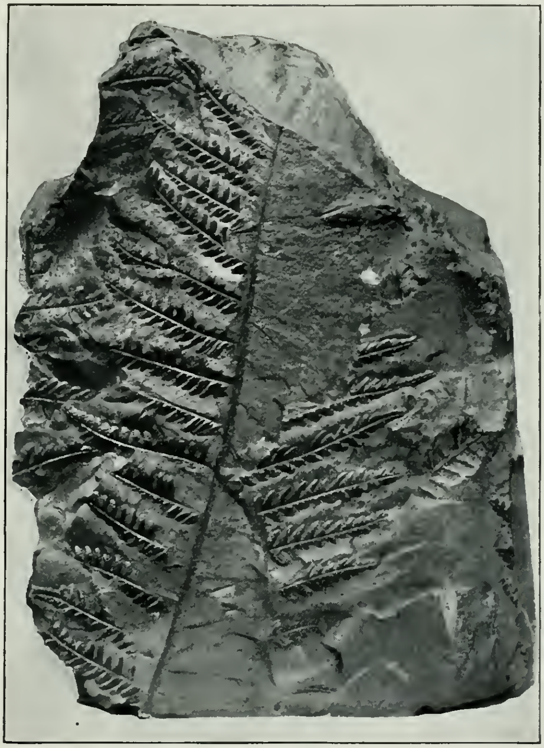

FIG. 2.—IMPRINTS OF A FERN-FROND IN A PIECE OF COAL.
(From a photo. taken in the Natural History Museum, South Kensington.)

It is worth our while, then, to know something about the nature and origin of this black combustible, which we exhume from its rocky bed with so much labour and patience, and upon which depends so much of our national prosperity.

If you take a lump of coal out of the coal-scuttle, you find yourself in possession of an irregular lump of black stone, which usually soils the hand that holds it to a greater or less extent. It generally presents one obvious feature—namely, that it consists of thin, parallel layers, some of which are usually shiny and glistening, while others are more dull and earthy in appearance. In consequence of this structure, as everyone knows who has ever stirred a fire, it is comparatively easy to break up a piece of coal in one direction (the direc-

tion corresponding with that of the component layers), but repeated blows from the poker may be vainly used if the refractory lump be attacked in the opposite direction—that is, at right angles to the layers. Now, as before remarked, there is nothing whatever about a piece of coal which would in any way indicate its inflammable nature, and perhaps the first question desire to unite itself with oxygen, which is present in large quantities in our atmosphere, this union being attended with the production of light and heat, and resulting in the formation of the invisible and poisonous gas which is commonly called carbonic-acid gas. When, therefore, we burn a piece of coal in the fireplace, what happens, roughly stated, is (1) that the

Photo: Cassell & Co., Ltd.

FIG. 3.—COAL-MINING: AT THE FOOT OF THE SHAFT.
(From a photograph taken in the Griff Colliery.)

that we should feel disposed to ask is, *Why* does coal burn?

To answer this question we must call in the help of our chemical friends; but we can get an intelligible reply without dipping very deeply into the theory of combustion. The chemist tells us, then, that coal is composed principally of the element carbon, seen in its purest form in lamp-black, charcoal, and the wonderfully dissimilar blacklead and diamond. He further tells us that carbon, when raised to a certain temperature, has the strongest carbon of the coal enters into direct union with the oxygen of the air, emitting heat and light in so doing, the invisible carbonic-acid gas thus produced escaping up the chimney; and (2) that the earthy and incombustible matter present in greater or less amount in all coals is left in the grate unburned, in the form of ashes and cinders, while there will be a greater or less deposit of soot in the chimney and flues.

Roughly speaking, then, coal consists of from 80 to perhaps 95 per cent.

of the element carbon, mixed with a small proportion of various mineral substances, which remain as *ash* when the coal is burnt. In addition to these constituents, however, coal contains, locked up in its interstices, a certain amount of inflammable gas, varying in quantity in different kinds of coal. The so-called "hard" coals, or "anthracites," contain least of this gas, and are consequently the most stony of all, with a shining, jet-black aspect, and burning with a bright red heat, without flame. Such coal does not readily burn in an open fireplace, but is largely used in furnaces. In some countries (as in North America) it is commonly used as a domestic coal, being burnt in scientifically constructed stoves, and valued for the intense heat which it gives out. Included in this section are the stony-looking clean kinds, known as cannel coals. Again, our ordinary household coal in this country contains a comparatively large amount of gas, for which reason it takes fire readily, and burns with a good deal of flame. There are numerous varieties of this kind of coal, but they may be all spoken of as "bituminous." These contain the largest amount of gas of all the coals, and are therefore highly valued and largely used in the manufacture of illuminating gas. The name of "cannel coal" (really "candle" coal) is probably based upon this, and alludes to the fact that this kind burns with a clear, bright flame.

FIG. 4.—MODERN BRITISH REPRESENTATIVES OF THE PLANTS WHICH MADE THE COAL MEASURES: *EQUISETUM LIMOSUM* IN A SWAMP.

Having obtained this general notion as to the chemical nature of coal, we may next consider the question as to its origin and mode of formation; and in this inquiry it will perhaps be an advantage to attack the problem before us in a somewhat roundabout manner. Let us first betake ourselves, then, to one of the great "peat-mosses" which are found so commonly in temperate and moist regions, and which cover such extensive areas in Scotland, Ireland, and the North of England. We may find a "moss" suitable for our purpose high up amongst the hills, or in some low-lying, marshy situation; but in each case the phenomena exhibited are much the same. If we look at the channel cut by any stream across such a moss, or a any artificial excavation, we find that the ground is composed of a substance which near the surface is of light colour and spongy texture, but that at greater depths

it becomes darker in colour and denser in structure, till at length it is quite black and earthy. This substance is what is called "peat," and everyone knows that when cut into slabs and dried it makes a very tolerable fuel, and one largely used in some parts of the country. Now, peat is chemically very much the same as a poor kind of coal, for it consists of about 58 per cent. of carbon, along with certain earthy impurities, which are left as "ash" when the peat is burnt. The reason why peat is not so good a fuel as coal is that its texture is so loose that it contains a much smaller amount of carbon in the same bulk, whilst the amount of ash is proportionately larger, and the quantity of water contained in it is enormously greater; thus anthracite coal contains about 94 per cent. of carbon. If, however, peat be subjected to powerful artificial pressure, and have its contained moisture expelled from it, it becomes quite compact and stony, and may be regarded as an artificial coal, from which it differs principally in not containing inflammable gas.

It is clear, then, that bog peat and coal have much in common with one another, and anything which will explain the mode of formation of the one will throw light upon the origin of the other. Fortunately, there is no difficulty in determining how peat is formed. It is undoubtedly composed of the remains of different kinds of plants, and principally of such as delight in moist situations. In our country, peat is mostly formed out of the plants known as "bog-mosses" (*Sphagnum*), which have the curious property of constantly going on growing upwards, throwing out new leaves above, while the lower portion of the stem decays. They thus form a dense mass of vegetation, saturated with water, and constantly rotting below, as the green and growing surface increases in height. Along with the bog-mosses one can often recognise in peat the leaves or stems of reeds, rushes, and other water-loving plants; and in many cases we find, often at depths of many feet, the trunks or branches of trees, sometimes with numerous erect stumps. To look at the thin, weakling stems of the sphagnum, we should scarce credit them with exercising so marked an effect upon the formation of the earth's crust. Yet these self-same weakling stems are largely responsible for the formation of the coal beds, not so much by the way in which their own decayed remains go to swell the general bulk, but rather by reason of the effect that they have, whilst yet living, upon the stems of living trees. The structure of these mosses is such that, like a sponge, they can readily take up great quantities of water. This the reader may verify for himself, for a handful of wet sphagnum moss may easily be squeezed nearly dry. The continual contact of these water-laden mosses with the stems of living trees invariably compasses the death of the latter. This matter also can easily be proved by experiment. Supposing, then, our peat moss or bog of to-day to be occupying the site of a primeval forest. For a time the trees grow and flourish, then there comes a sinking of the land, a hollow is formed, water collects and remains, kept there by the deposit of clay at the bottom, the mosses grow apace, and the death of the trees follows, some of the stems previously referred to being left standing (Fig. 5) to tell the tale of vanished forest pride.

Such being the origin of peat, there is a reasonable probability that coal is formed after a somewhat similar fashion; and we have the means of raising this probability to an absolute certainty. Before, however, further examining actual coal itself, we shall briefly consider two other kinds of rock, one of which is very like ordinary coal in most respects, whilst the other presents no outward resemblance to it at all. To see the latter in place, we must transport ourselves in imagination to a small, low, densely-wooded promontory on the southern shore of the mighty Lake

Huron, which rejoices in the far from euphonious title of Kettle Point. Long, black ledges of rock run out into the blue waters of the lake, and the use of the hammer at once shows us that we have here to deal with one of those soft, muddy rocks, easily splitting into thin layers, which geologists are in the habit of calling "shales." This is not a coal, then? No! it is not a coal; but you can easily satisfy yourself that it has one of the properties of coal, for it will readily burn, and with a bright flame. A closer inspection will show that it is in other respects different from ordinary shales, for the surface of the layers is covered with little round brown specks, smaller than the head of a small pin, though quite visible to the naked eye. To make out these satisfactorily, we must take a chip of the rock and grind it down till it is so thin that it can be examined by the microscope (Fig. 6), when we find that each little brown speck is a minute bag—sometimes empty, sometimes filled with still more minute granules.

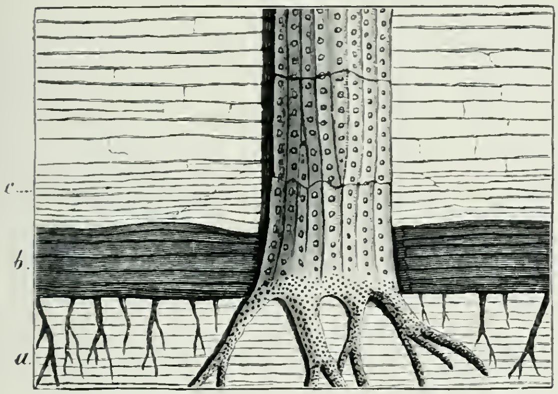

FIG. 5.—DIAGRAMMATIC VIEW OF A COAL-SEAM, AS SEEN IN THE FACE OF THE WORKING OF A COAL MINE.

a, Under-clay, with roots passing through it; b, bed of coal; c, "roof" of the coal, composed of sand and shales, with upright trunks of trees passing through it.

What, then, are these little bags? The botanist will tell us at once that they are the spore-cases of plants resembling our living club-mosses. The spores, which we may liken to the seeds of flowering plants, contain a great deal of resin in their outer covering, which enables them to resist decay for a long period, and also imparts to them their highly inflammable character. The Kettle Point shale, therefore, is nothing more than an old deposit of mud, charged with the spores of club-mosses, and now hardened into rock; and we can understand its mode of formation quite well by means of an analogous phenomenon which is commonly to be observed in Canada. The wanderer in the Canadian forests is often surprised to find the margin of the lakes covered with great banks of a yellow powder, looking somewhat like sawdust, only of a finer grain. This powder is really the "pollen" of the fir-trees, which is blown by the wind in great clouds—popularly called "showers of sulphur"—through the illimitable pine-forests. Extensive accumulations of this powder are driven up by the waves upon the muddy shores of the lakes, and if hardened and consolidated they will form a rock very similar to the combustible shales of Kettle Point.

We may next glance for a moment at the "Lignites" or "brown coals," which are so largely worked for fuel in Germany and Austria, and to a less extent in Britain and in North America. These lignites are

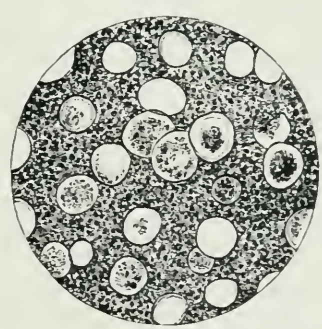

FIG. 6.—HOW SHALE IS FORMED: A THIN SLICE FROM KETTLE POINT, LAKE HURON, UNDER THE MICROSCOPE.

The minute spore-cases may be easily seen.

found in the form of beds, associated with sandstones, clays, and other rocks—just as beds of coal are found—and though inferior to good coal, they burn quite well. The name of "lignite" (Latin, *lignum*, "wood") refers to the fact that they are often obviously and conspicuously composed of petrified *wood*, showing the stems, branches, and leaves of trees quite distinctly. The name of "brown coal," again, is an allusion to the general brown colour of this fuel. Some lignites, however, are quite as black as coal to look at, and could not be distinguished from ordinary coal by the eye alone. That lignites are composed or hardened vegetable matter, as just mentioned, is often so clearly the case, that the most superficial inspection betrays the original fibres of the woody stems composing it crossing each other in all directions. If any doubt could remain upon this point, it is entirely removed by a microscopic examination, which proves them to be almost wholly composed of compressed stems, branches, and other portions of plants. We may therefore regard lignite as a kind of peat, which has been changed by being buried in the earth, and thus subjected to great pressure for long periods of time. At the same time most lignites are of a different origin from peat, for they seem to have been generally formed, to begin with, as accumulations of drifted logs and vegetable *débris* of all sorts, carried down into lakes or seas by rivers, and ultimately covered up with sand or mud. Similar accumulations are known to be in process of formation at the mouths of our great rivers at the present day, and when buried by sediment they will form the "brown coals" of coming epochs.

Let us now return to coal itself, and see, as shortly as possible, what are the data, direct or analogical, which we can command in reasoning out its origin and mode of formation. In the first place, then, we have the chemical information that coal is principally composed of carbon, in which respect it agrees with peat and lignite, both of which are of undoubted vegetable origin, as well as with wood and the tissues of living plants in general. This fact of itself, therefore, would raise a strong presumption that coal is formed of vegetable matter. In the second place, if we examine coal carefully, even with the unassisted eye, we shall have no difficulty in seeing that certain parts of it have a distinct fibrous structure (in many cases, at any rate), thus so closely resembling charred wood or charcoal, that the name of "mineral charcoal" has actually been given to these portions as a technical term. Moreover, if we had to do much with coal, and were in the habit of examining large quantities of it with any care, we should often find in it portions of the stems and leaves of plants so well preserved that we could not doubt as to their nature (*see* Fig. 2). Fortunately, however, we are not left to rely alone upon our unaided vision, and this is one of the cases in which the microscope affords us invaluable help. Black and opaque as it is, coal can nevertheless be ground down into slices so thin as to be quite transparent, and thus capable of examination by our modern optical instruments. When examined in this way, we find that coal is invariably composed of vegetable matter of one kind or another. Some coals are composed almost wholly of portions of the stems, branches, and leaves of different kinds of plants, and thus may fairly be compared with an intensely consolidated peat. Other coals, again, as shown by Professor Huxley, are principally composed of the minute globular "spores" of plants related to our living club-mosses; and these may be regarded as being essentially of the same nature as the shales of Kettle Point, on Lake Huron, of which we have previously spoken.

We have, thus, direct and incontestable proof that coal is altered and hardened vegetable matter, and that it is formed out of the remains of ancient plants; but there are some other facts still which require to be considered before we come to a final

conclusion as to the method in which it was formed. Coal is found in beds or "seams," varying from perhaps an inch up to sometimes as much as sixteen or seventeen yards in thickness, in the crust of the earth, associated with beds of sandstone, clay, and limestone ; and a good deal may be learned by examining its mode of pendicular roots of plants (Fig. 5). This "underclay," as it is called, is therefore clearly the old soil in which the coal-plants grew. Again, there generally rests upon the seam of coal a bed of shale or sand, which is called the "roof" of the coal, and in which we find innumerable stems and branches of different kinds of plants.

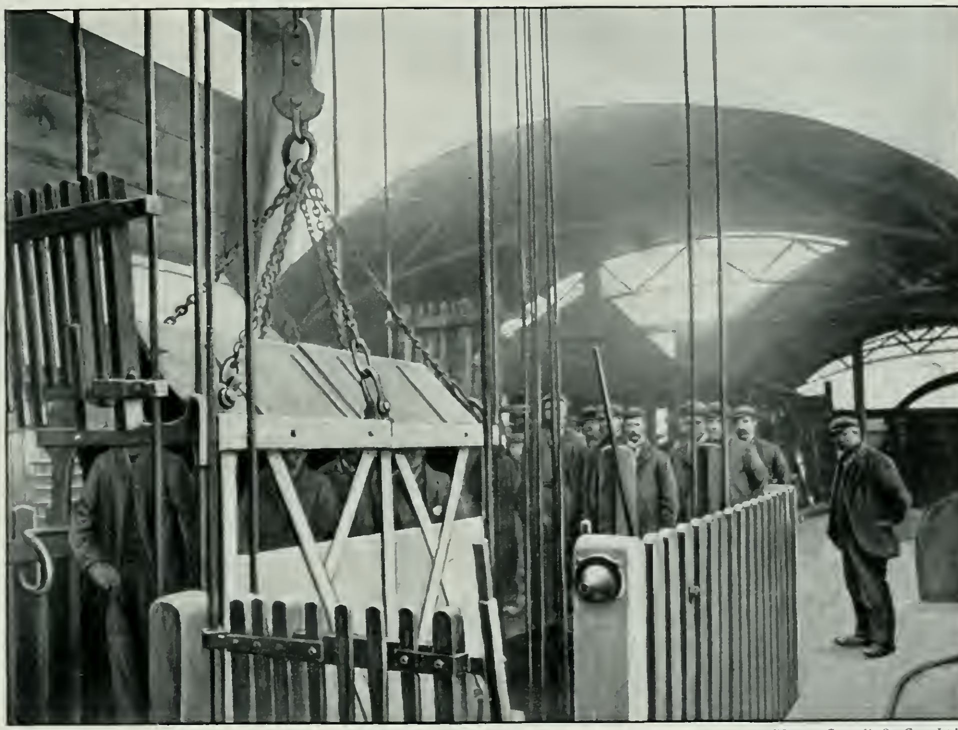

Photo: Cassell & Co., Ltd.

FIG. 7.—LIFE IN A COAL MINE : THE CAGE BY WHICH DESCENT AND ASCENT ARE MADE.
(From a photograph taken in the Griff Colliery.)
This cage is worked by powerful machinery, and it only takes about 18 seconds to accomplish the descent of 1,000 feet.

occurrence on a large scale. We cannot here enter into the many interesting facts which are known as to the geographical and geological distribution of coal, but there are one or two points which bear so directly upon the question of its origin that they cannot be omitted. The most important of these is a fact long ago demonstrated by Sir William Logan, and since confirmed by many other observers —namely, that every bed of coal rests upon a bed of clay—now hardened into "shale" —which is penetrated by numerous per-

Lastly, it is far from uncommon to find in the coal itself, or in the beds which immediately surmount it, the trunks of trees still standing in an upright and vertical position.

The above-mentioned facts render it indubitable that the coals which we burn were not only formed out of the remains of old vegetations (*see* Fig. 1), but that they were formed from plants which actually grew in the spot where we now find the coal. Some beds of coal have doubtless been formed, like many of the lignites, out of vege-

table matter, drifted out into a lake or sea by rivers; but this has been clearly exceptional, and most coals have been unquestionably formed by the uninterrupted growth and decay of successive generations of plants in the places where these plants grew. In this respect coal is like peat, from which it differs principally in the nature of the largely into the composition of the coal itself, and we are, therefore, not reasoning in the dark when we try to reconstruct for ourselves the vegetation of this wonderful epoch in the history of the world.

It is impossible here to enter into minute details, interesting though they be, as to the nature and structure of these old

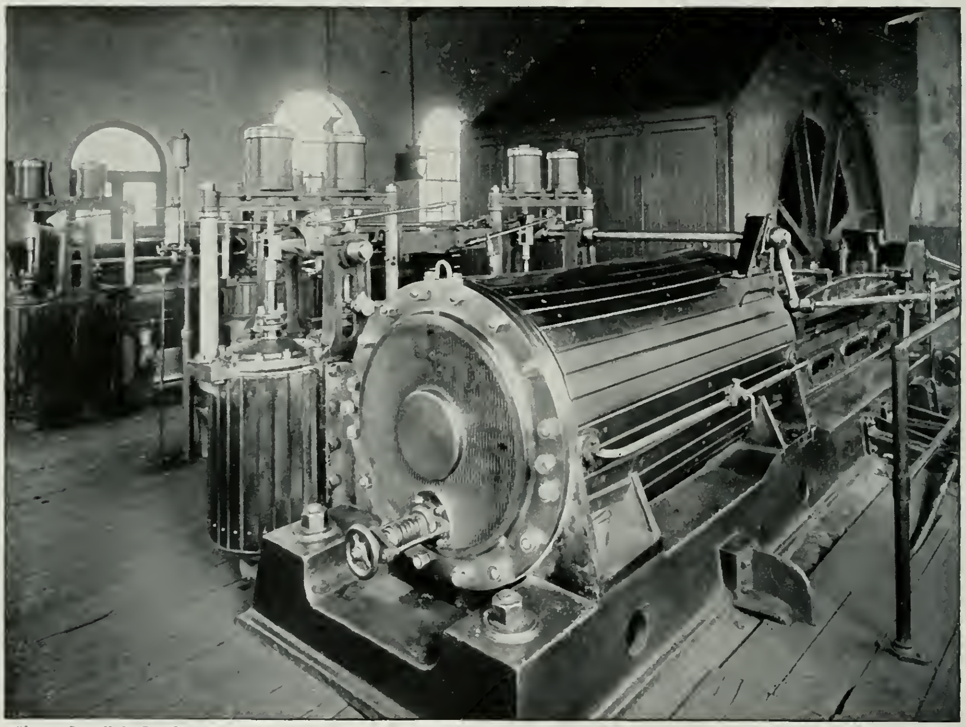

Photo: Cassell & Co., Ltd.

FIG. 8.—THE WINDING, VENTILATING, AND PUMPING MACHINERY AT THE GRIFF COLLIERY.

In this room what may be called the "brains" of the mine are situated. It needs but a touch of the lever to send the huge "cage" up or down as required.

plants of which it is composed. Peat is formed mainly by the growth of plants such as the bog-mosses, sedges, and rushes, which not only inhabit moist and comparatively cold situations, but do not in themselves attain any great dimensions. On the other hand, the vegetation which gave rise to the coal was of the most rank and luxuriant character, and is, apparently, indicative of a climate not only moist, but also warm. We are now acquainted with some hundreds of plants which lived during the coal period, and enter more or less plants, and it must be sufficient to say that they belong to four principal types. In the first place, we find a very large number of ferns, some of them comparatively small and with soft tissues, resembling our own common ferns, whilst others were of much larger dimensions, and may be compared to the giant "tree-ferns" of New Zealand and South America. Secondly, we find a vast number of plants allied to our living club-mosses, but of comparatively gigantic dimensions, and attaining the size of our ordinary forest

Photo: Cassell & Co., Ltd.

FIG. 9.—SORTING AND CLEANING BLACK DIAMONDS

(From a photograph taken in the Griff Colliery.)

trees. The most remarkable of these are the forms known as *Lepidodendron* and *Sigillaria*; and trunks of the latter, in particular, are not uncommonly found in an upright position in the beds associated with the coal-seams. Thirdly, we have the singular plants which are known as *Calamites*, and which are to be regarded as ancient but gigantic representatives of the little horse-tails (*Equisetums*) (Fig. 4) of the present day. These curious plants, with their long, striated stems, seem to have grown in dense brakes or jungles, and often attained a height of twenty feet or more; few of our living horse-tails exceeding two or three feet in height. Lastly, we meet with a considerable number of true trees, related to our living yew-trees and pines, and sometimes of great size.

Coal, then, may be regarded as essentially composed of the more or less crushed and compressed remains of the leaves, branches, stems, and seeds of different firs, calamites, ancient club-mosses of the type of *Lepidodendron* and *Sigillaria*, and ferns. The great majority of these plants are "flowerless," and they indicate a dense land vegetation, growing in low, marshy situations, and in a comparatively warm climate. Countless generations of plants must have lived and died before the dark and rich vegetable mould could have accumulated to a thickness sufficient to account for the production of even one foot of coal; but at last we must suppose that the old land-surface commenced slowly to sink beneath the sea, and the once verdant plains were gradually covered by the salt water of the ocean. The so-called "roof" of the coal thus represents the first accumulation of sediment thrown down upon the nascent coal-bed, and we can readily understand how it should be so rich in the stems and fronds of ferns and other plants, and how it should often be traversed by the upright trunks of trees.

In this way, then, we can explain the method in which a single bed of coal is formed. In a single coal-field, however, we may find fifty to perhaps one hundred beds of coal, lying one above the other, and separated by intervening beds of clay and sand. In this case, we have to suppose that after the formation of the first bed of coal, in the manner above indicated, the old land was again raised above the level of the sea by one of those movements to which the crust of the earth has been so often locally subjected. Soon, a vegetation as rank and luxuriant as its predecessor flourished on the newly born plain, and vegetable matter was again accumulated throughout a long period of rest and stability. Then the land once more sank slowly beneath the sea, and sand and mud were once more heaped up over the vegetable *débris* of centuries. In this way a second bed of coal would be formed; and it is easy to understand how, by a repetition of these alternating movements of elevation and depression, affecting great tracts of land raised but little above the sea-level, any required number of coal-seams might be formed in succession in the same area.

The vast deposits of fossil fuel which have so largely contributed to place Britain in the first rank of commercial nations are thus the indurated and compressed fragments of ancient vegetations which lived and died long geological epochs prior to man's first appearance on the earth. The light and heat of our fires are, in strict scientific truth, the "bottled-up sunlight" of past ages. Nor is it easy to over-estimate the amount of time demanded for the accumulation of these great stores of carbon. An eminent chemist has calculated that the dense vegetation of the tropics produces about fifty tons of carbon to the acre of ground in a hundred years; but fifty tons of coal spread evenly over an acre of ground would not make a layer of half an inch in thickness. What, then, are we to think of the time required for the formation of a seam of coal one yard in thickness, not to speak of such giant seams

as the "Ten Yard Coal" of South Staffordshire? There would be something almost painful in the reflection that we are rapidly expending these long stored-up and carefully elaborated accumulations, if we did not, at the same time, know that our very expenditure is the means of returning to the atmosphere the materials out of which new deposits of carbon will ultimately be produced. Even from the black and dusty coal may we thus learn to recognise with admiration some portion of the checks and counterchecks, the balances and compensations, by which the system of nature is preserved in equilibrium.

The remainder of the illustrations which accompany this article need no further description than has been placed beneath them. For the most part they represent scenes in the working of a coal mine, and themselves describe, far better than mere words, what goes on.

Photo: Cassell & Co., Ltd.

FIG. 10.—INTERIOR OF MINE, SHOWING SUPPORTING TIMBERS.

To guard against a collapse the roofs of the numerous galleries with which the mine is honeycombed have to be carefully "shored" up with heavy timbers. The least neglect or carelessness in the work may have to be paid for by a heavy toll in human lives.

SUNSET, TWILIGHT, AND HALOS.

IT is not generally realised that the atmosphere which surrounds the earth has as much effect on the rays of light coming to it from the sun as if it were a roof of orange-coloured glass. According to the accepted view of the matter, the solar energy travels to the earth in vibrations that vary from a wave length of less than ·0003 mm. to one that is indefinitely greater. Further, some of these vibrations affect the eye with the sensation of light ; others reveal their presence by their chemical action, being called the *actinic* rays ; while all the rays are carriers of heat. Heat and chemical action are, of course, subjects of independent observation and research, but in contemplating such phenomena as sunset, twilight, and halos the attention is more especially concentrated on the radiant energy that manifests itself as light.

Now, as already stated, one of the most important things to bear in mind as regards the rays of light that journey to the earth is that they pass through a very turgid medium. On any fine sunny day, when the sky is cloudless, the atmosphere seems very tenuous and transparent, but in reality it has enormous weight, the weight of the air over any large city, for instance, being much greater than that of all the buildings over which it is floating. In addition, the atmosphere is crowded with minute particles of aqueous vapour that, among other things, take the form of clouds, ice crystals, fog, mist, and haze, which serve to build a screen that is perpetually poised between the sun and the earth. Moreover, modern research has recognised the existence of atmospheric dust that is considered to pervade the air in its every part. This dust may find its way into the air by the agency of volcanoes, meteors, and the strong ascending currents of air that rise from all parts of the earth, a further source of atmospheric dust being the tiny crystals of salt that are contributed by the sea. These and other forms of atmospheric dust and the aqueous vapour combine, therefore, to build up a canopy that exerts some remarkable modifications on the rays of light that plunge through it. What this canopy does is to absorb some of the rays, so that, just in the same way that a ray of light admitted to a room through a crevice in the shutter is not so bright after passing through the dusty atmosphere, the rays of light coming from the sun are diminished in brightness, or absorbed, by the atmosphere surrounding the earth.

In recent years this subject of atmospheric absorption has more particularly been investigated by Professor S. P. Langley, who conducted a series of observations for the United States Weather Bureau at the top of Mount Whitney, California. From these observations it was concluded that the atmosphere had not merely kept back a part of the solar radiation, but had totally changed its composition in doing so. The familiar white light is, indeed, only a residue, and does not truly represent the colour of the rays when they originally started on their journey from the sun to the earth.

Supposing, therefore, that one could see the sun from a position outside the earth's atmosphere, the sunlight would be seen to be blue, or, more correctly, blue would be the dominant note in the colour scheme. What the atmosphere does is to absorb the greater part of these coloured rays, so that, as regards an observer on the earth, it

SUNSET IN THE ALPS: THE GRIVOLA, FROM VIEYES.

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is much as if he were looking at an electric light shining through a reddish glass shade. This, then, is the starting point to bear in mind when observing sunsets and their dependent phenomena—namely, that they are primarily the result of blue light passing through an orange-coloured atmospheric screen.

Now this investment of air stretches far out into the void of space, so far, indeed, that, like a mountain-top, it catches the rays of the sun upon its topmost heights. These shining aërial heights are then, in this particular, like the summit of a mountain tipped with sunshine, whilst the valley at its base is still dark with the shadow of night. The air-summit, indeed, is so much higher in its stretch than the loftiest of the mountains that, as a matter of fact, it is basking in the light when their tops are still covered with gloom. The twilight, which is so familiar to everyone, is thus properly the top of the air, tinged with the rays of the horizon-hidden sun. Small as the air-particles are in their isolated individualities, they nevertheless cluster round the earth in such overwhelming abundance, and crowd behind each other in such densely serried ranks, that they shine through their depth under the far searching rays as an impenetrable, solid surface might do. The twilight may thus, in strict accuracy, be defined as the summit of the air illuminated by the direct beams of the rising or setting sun, and seen from the regions below, which are still covered by the sable shadow of the earth.

The heights of mountains can be calculated by skilful mathematicians from the length of time which elapses after the first touching of their highest peaks by the beams of the sun before the face of the luminary itself rises into light on the low ground around their base. The higher the peak, the longer the interval which thus intervenes. This is most easily understood from a consideration of the way in which the heights of the mountains in the moon have been measured by astronomers (Fig. 1). All the chief mountains in the moon, which can be seen from the earth by the help of a telescope, have had their heights ascertained in this way. The German observers Beer and Maedler calculated the heights of not less than one thousand and ninety-five lunar mountains. As the front edge of the sunshine sweeps over the spherical surface of the moon, sparkling islands of light start up in the darkness, in advance of the boundary of the spreading illumination. These are all mountain-tops which have caught the sunbeams before they have reached the lower valleys round. The appearance of these isolated specks of brilliant light, dotted out in front of the general field of sunshine advancing upon the face of the moon, is one of the most interesting of

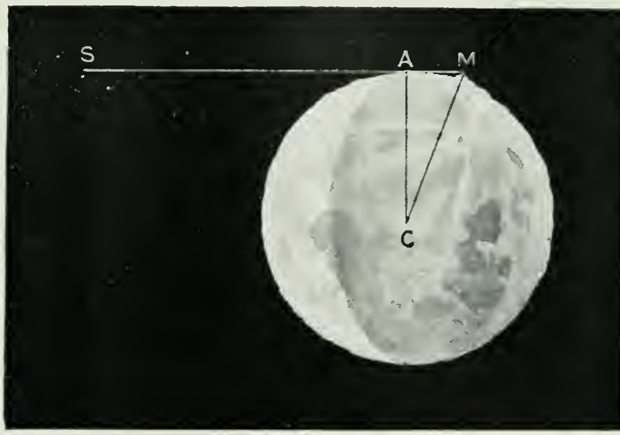


FIG. 1.—HOW THE MOUNTAINS IN THE MOON ARE MEASURED.

The circle represents the moon; S A, the line along which the light from the sun passes; C, the centre of the moon; M, top of the mountain to be measured. A M is the distance of M from the illuminated portion; C M, the distance of M from C. C A and A M being known, and C A M a right angle, the length of C M is easily calculated by trigonometry.

the spectacles which have been provided for human sight by the power of the telescope, the process by which the heights of the mountains are found—by measuring the distances of these shining spots from the boundary of the general illumination of the moon—being a simple application of one of the fundamental principles of trigonometry. By a similar process the attempt has been made to ascertain the height of the outermost layers of the air. It is observed how far the sun has to sink beneath the horizon before the topmost summit of the air is cut off from its rays. A competent authority, M. Bravais, some years ago made a series of observations of this character from the top of the Faulhorn, a mountain over 8,800 feet high, and standing between the Lake of Brienz and Grindelwald in Switzerland, and he concluded that the extreme upward range, or limit of the twilight, was placed 378,000 feet, or nearly seventy-one miles, above the level of the sea.

The exact definition of twilight is not, however, an altogether settled matter. It was at one time conceived that twilight lasted until the sun was eighteen degrees below the horizon, and then ceased. As a matter of fact, this is an altogether unsatisfactory and illusory conception. There is sometimes a very bright twilight long after the sun has reached this depression, and at other times there is absolute darkness considerably before. Alexander von Humboldt found that the duration of twilight was restricted to a very few minutes in the inter-tropical regions of South America, or, as Coleridge describes it, "The sun's rim dips, the stars rush out, at one stride comes the dark." It endures a quarter of an hour at Chili, and half an hour upon the slopes of the Eastern Alps. When the air is heavily laden with vapour, or with particles of snow, there is occasionally strong twilight until the sun is quite 30° below the horizon. The common rule-of-thumb test for the duration of twilight is the ability to perceive ordinary objects in the open air. The astronomer's estimate is based upon a more exact and therefore more serviceable indication. The twilight is conceived by it to be at an end at the instant that a sixth magnitude star can be seen twinkling in the sky high overhead. This, upon the whole, is perhaps as good and practical a standard as can be adopted.

But the twilight is not the only visible manifestation that the subtle aërial investment makes to the eyes of man. On any sunshiny day there is always the blue sky to be seen, which in the absence of clouds reveals itself as the hemispherical vault of the firmament. "What makes the sky so blue?" is a question that naturally arises in an observant mind. Briefly, the light thus returned to the eye is blue, simply because the particles of the air are of such exceedingly diminutive size that they can effectively deal with only the smallest of the luminous vibrations—that is, with the blue undulations. There are some faint and subordinate interminglings of the other coloured rays in the blue of the sky, but they are in such trifling quantity compared with the blue that they are practically swallowed up and lost in its superior abundance. They can only be detected in the preponderant flood of blue, and rendered sensible to the eye, by the subtle processes with which exact science and skilful manipulators are competent to deal. The effect, obviously, must be due to the reflection of light that has come from the sun. Professor Tyndall alludes to this view of the case very forcibly. He remarks, in a lucid discussion of this question, "Proofs of the most cogent description could be adduced to show that the light of the firmament is reflected light. The light of the firmament comes to us across the direction of the

solar rays, and this lateral and opposing rush of wave-motion can only be due to the rebound of the waves from the air itself, or from something suspended in the air. The solar light, moreover, is not reflected by the sky in the proportions which produce white. The sky is blue, which indicates an excess of the smaller waves."

Of all the causes, however, that thus filter out the blue light, none is equal in importance with the effects produced by the atmospheric dust. Thanks to the researches of Mr. John Aitken, meteorologists nowadays are learning to give this agency a much more prominent position in their cogitations than was the case formerly. By means of an ingenious apparatus called a "dust counter," Mr. Aitken has tested samples of air in many parts of the world, and he has found that at the mountain tops, as well as in the cities and the valleys, it is impossible to find a sample of air that is not crowded with these dusty atoms. The majority of them are exceedingly small, and in many instances so minute as to be invisible even to the strongest microscopes. The only way, indeed, by which the presence of these dusty atoms is discovered is by noting the work they perform, one of their chief operations being to produce the blue sky. As might be expected, the lower strata of the atmosphere are the most crowded with these dusty loiterers, an illustration of this congestion being afforded by the fogs which occur when the carbon and other particles are settling downwards in myriads. But far above these layers are the atoms of dust that are projected many miles above the surface of the earth. It has sometimes been suggested that after some great volcanic eruption—such as that at Krakatoa—the atmosphere would soon free itself of dust, but in reality such dust remains floating for years.

FIG. 2.—"LAST NIGHT THE MOON HAD A GOLDEN RING."

As previously mentioned, the rays of light coming from the sun are of different

wave lengths, but they are also modified by the varying sizes of the atoms of dust against which they strike during their journey through the air. Many of the atoms, moreover, are of smaller dimensions than the wave lengths of light surging past them, and hence it is that the red and the orange rays, for instance, pass over these obstacles, while the shorter-length blue rays are impeded. They are, indeed, turned out of their path, and are scattered, and it has been suggested by Lord Rayleigh that it is to this selective scattering of the finer rays of light by the still finer atoms of atmospheric dust that the blue colouring of the sky is due. The process has been illustrated by directing the attention to the appearance of a bottle of soapy water when a beam of light is made to pass through it. Seen thus, the water has a yellow or orange tinge, but viewed sideways the liquid takes on a blue colour. Similarly, therefore, as regards the sky, it is probable that the sunbeams upon collision with the particles of dust have been scattered in such a way that a blue tint has been filtered out.

Interesting, however, as are the phenomena connected with twilight and the blue sky, they lack the impressiveness of a gorgeous sunrise or sunset, while from a spectacular point of view they must yield place to the brilliant colours so frequently painted on the clouds. In recent years no such opportunity for studying sunsets and after-glows has occurred as during the autumn of 1883 and for a considerable time afterwards. During this period, three noteworthy optical phenomena occupied the attention of observers in all parts of the world. First there were sunsets and sunrises of a most bewildering colouring, the after-glows and fore-glows being of uncommonly long duration and unusually rich. Secondly, the sun itself assumed unaccustomed tints, and appeared in some places as if it were seen through green, red, or blue glasses. Thirdly, there were the halos and other accompanying phenomena that formed with abnormal frequency round the sun, moon, and certain of the brighter stars. At all times these phenomena are to be observed, but, as already mentioned, their study received a great impetus during the year in question. It will perhaps be remembered that this was the year in which occurred the tremendous volcanic eruption at Krakatoa, in the Straits of Sunda, an eruption that threw vast clouds of dust into the atmosphere, and was, indeed, the prime source of the magnificent sunsets and after-glows referred to above.

The gorgeous colours of the clouds, which occasionally present so beautiful a spectacle before sunrise and after sunset, depend mainly upon the circumstance that the aqueous and dusty particles which they contain are of such large size, in comparison with the dimensions of the undulations of light, as to enable them to reflect all the colour-constituents alike —the largest as well as the smallest—the coarse oscillations of the red and yellow, as well as the exquisitely delicate vibrations of the blue. As the sun sinks towards the horizon, and the aërial distance through which the rays have to pass increases, more air-particles of necessity lie in their path, and more and more of the less refrangible coloured rays are arrested with the augmenting length of the track; first the blue, then the green, afterwards the yellow, and finally the orange and red. Consequently, although the light reflected from the sky at noon comprises only the weak azure vibrations, that which is reflected from the vapours and clouds after sunset may consist chiefly of the crimson rays which have made their way up through the long air-track, and which are thence thrown back to the eye. Professor Brücke, indeed, con-

structed an artificial sky by dropping a spirituous solution of resin into water until the liquid became turbid and milky. When a black board was placed behind the glass containing this turbid solution, and the light allowed to fall upon the liquid obliquely from above, it assumed the aspect of a clear blue sky. Professor Helmholtz, indeed, very unpoetically, and almost irreverently, speaks of a blue eye as simply an eye with turbid humours.

The gorgeous colours of the sunset clouds are thus due to the circumstance that the yellow and red rays of light have more penetrative momentum than the blue. They make their way through stretches of the atmosphere which entirely arrest and turn back the blue, and they do this the more especially if the air is laden at the time with extraneous particles that augment the aërial opacity. When the sun is below the horizon, and streaks or layers of clouds are hanging above it in the atmosphere, at heights which still enable them to receive illumination from the bright luminary, the red and yellow rays struggle on through the air as far as these clouds, dropping their blue associates by the way, and thus paint their fleecy surfaces with red- and yellow-tinted light. The colours that so commonly appear towards the eastern side of the sky after sunset are virtually reflections of a secondary kind, shot off from the cloud-surfaces upon which they have first fallen, so that they ultimately strike upon other clouds in remote parts of the firmament, and are from them returned to the eye. There is also a secondary or eastern twilight, of a quite analogous nature, which faintly illuminates the remote side of the sky after sunset, and which is simply the glancing of the twilight of the west off towards the east, from the air-particles that catch the rays in the first instance.

In the opinion of Professor Kaemtz, the well-known meteorologist of Halle, the green tint so often seen at sunrise is due to the blending of the ordinary blue light of the sky with the yellow rays incident to the sunrise; and this view of the case accounts for the notorious circumstance that the recently risen or nearly setting sun is so rarely green. The weak blue rays are stopped off when the direct

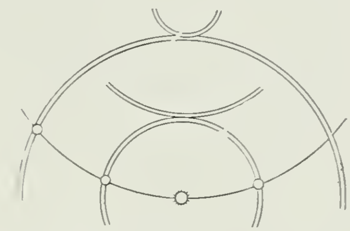


FIG. 3.—A SIMPLE FORM OF HALO, SHOWING MOCK SUNS.

sunshine is passing through the dense and possibly vapour-laden layers of the atmosphere. But whenever it is one portion only of the chromatic constituents of the light that is thus filtered off, the strong yellow and orange rays are the residual parts that make their way through.

When, with an otherwise unclouded blue sky, the western horizon assumes a purple tint after sunset, this almost certainly gives promise of the prevalence of fine weather. When, after rain, the clouds are strongly tinted with ruddy light, the augury is of a like good character. A whitish-yellow glare, ensuing after the setting of a brilliant white sun, is very frequently followed by rain. Deep ruddy tints over the eastern horizon before sunrise generally indicate the approach of rain, whilst a grey and colourless eastern sky before sunrise gives promise of fine weather. The reason for this apparent anomaly simply is that the ruddy light is for the most part caught in the evening by high *cirrus** clouds, which are the clouds of a dry atmosphere, and

* *See* "Clouds and Cloudland," CASSELL'S POPULAR SCIENCE, Vol. I., p. 442.

in the morning by dense *stratus* clouds, which are connected with the increasing precipitation of aqueous vapour. When there is enough vapour in the air in the

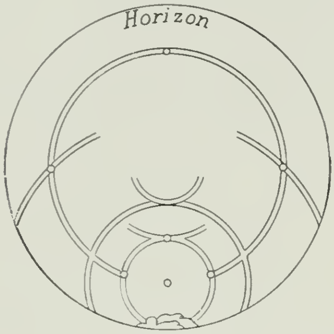


FIG 4.—COMPLICATED HALO, RARELY SEEN.

early morning to furnish red clouds, it is almost certain that denser clouds will gather with the advance of day.

Together with the after-glows and an unusual coloration of the sun, another optical phenomenon has from time to time been observed. After the observer who first noticed it, this has been called "Bishop's Ring," and consists of a reddish ring that surrounds the sun at a distance of from ten to twenty degrees, and is most commonly seen when the sky is comparatively clear. This ring has been seen both in the tropics and in the temperate zones, and was especially noticeable during the months that followed the volcanic outburst at Krakatoa. The boundaries, indeed, within which this phenomenon was observed seemed clearly to indicate that it was produced by the extremely fine atoms of volcanic dust floating in the higher parts of the atmosphere.

Complete circles of faintly coloured light are sometimes formed round the moon on nights when the sky is thinly veiled with haze (Fig. 2). The iridescent rings in such circumstances are familiarly spoken of as lunar glories, or halos. In its most characteristic and complete state the circle has a diameter of 45° of the celestial sphere—that is, it is a ring-shaped band of light concentric with the moon's face, and just forty-five times that luminary's own breadth away from it. The colour is generally very subdued, but it is occasionally so well pronounced as to render the halo liable to be mistaken by unpractised observers for a lunar rainbow. The distinction is, nevertheless, absolute and clear. The halo encircles the moon, and therefore appears on the same side of the sky, whereas the rainbow of necessity presents itself on the side of the sky which is opposite to the moon. The observer stands with his face to the moon whilst looking at a halo, but must have his back to the moon whilst he is contemplating a rainbow. Circles of a similar character are occasionally formed round the sun, but they are not as easily observed on account of the overwhelming glare of the solar light. Whenever the colour is well developed it is found that there is a red tint at that edge of the luminous band which is nearest to the moon or sun, and a blue one at the opposite margin. The halo thus produced round the moon or sun is due to the influence of minute prism-shaped crystals of ice, floating in great abundance in the higher regions of the air. Readers of these pages are aware that, if a sunbeam is allowed to fall upon a three-sided bar or *prism* of glass, it is bent out of its original course as it passes through the prism, and, at the same time, broken up into a diverging sheaf of coloured rays. The ice-prisms, which float suspended in the upper regions of the atmosphere, exert a similar influence upon the light that passes amongst them.

When an observer is looking at a halo encircling the moon, in order to understand what is taking place he must endeavour to conceive that at the distance of 23° from the apparent position of the moon the "ice-prisms" stand in such a relation to the light which is thrown off

to them from the shining surface of the luminary as to bend down towards the eye a comparatively large proportion of the rays. A very considerable number of the ice-prisms which happen to lie at that precise distance are so ranged as to conspire to throw the luminous beams towards the eye, rather than in any other direction ; and, as this takes place at the same distance all round the moon, the luminous band appears as a ring. The ice-crystals are scattered in the air in all conceivable positions. But, in consequence of the particular form of the crystals and of the special power of that form over the vibrations of light, only those which occupy the specified distance and range deal with the rays in this way. The reason for this result is, perhaps, one which can hardly be explained satisfactorily in familiar and unmathematical language, but it is connected with the circumstance that, in certain specific positions, a prism exerts less bending upon transmitted rays than it does in others. That such is the case may be experimentally proved if a prism of glass is turned round upon itself when a sunbeam is falling upon it. The divergence of the beam from its original course is then seen to alter with the revolution of the prism, but, in one particular position, it takes more turning of the prism to produce any given amount of deviation. A great number of the ice-prisms that are placed where the halo appears in the sky are in that position on account of the relation in which they stand to the moon and the eye, and conspire to produce the luminous band. The size of the circle of the halo is determined by the fact that the emergent light issues from the terminal face of each prism at a fixed, definite angle. The halo most commonly seen has, as has been already said, an apparent diameter of 45°. But halos of rather more than twice this diameter are occasionally produced. In such circumstances the light is more faint, and it is almost always devoid of colour. In these instances the light issues from the prisms at an angle of 46° of deviation from its original course, and this larger deviation appears to be due to the rays being emitted from the ends of the prisms rather than from their sides, and where the end and side meet each other perpendicularly.

Associated with the halos are the *parhelia* and *paraselenæ*, or "mock suns" and "mock moons." These objects are accompanied by a duplication of the primary halo, the circles being in many cases only fragmentary, but it always happens that the mock sun or moon appears at a point where the circles cut one another. Sometimes only the fragmentary circles are to be seen, like portions of a broken rainbow, and in these circumstances they have in popular nomenclature received the name of "sun-dogs." The sun-dog may at times vary slightly as regards its length or breadth, but never as regards its relative position to the sun. Taking, therefore, the sun as the centre of the circle, the sun-dog always appears at the point where

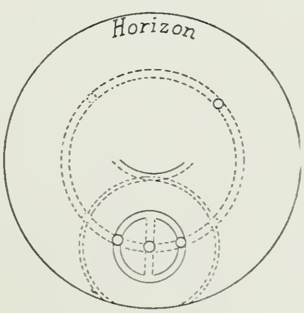


FIG. 5.—A COMMON TYPE OF HALO.

vertical and horizontal lines, passing through the centre of the sun, would cut such a circle. Moreover, the side of the sun-dog facing the sun is invariably concave, and forms an arc of a sometimes visible but most frequently invisible circle

or halo round the sun. Further, the dogs on each side of the sun may appear either singly or together, but according to some observers a dog never appears above or below the sun without the side ones being also in view. Commonly, when the sun-dogs are observed, the sun is at an altitude of about 45°, and it has been suggested that much of the curious appearance is due to perspective, which from the point of view of the observer causes the particular focus of the sun's rays. The mock suns and moons, it has been further suggested, are the effect of mirage. Commonly they occur with a very low temperature and an exceedingly clear atmosphere, and are, indeed, most favourably observed in arctic latitudes.

The so-called "coronas" of coloured light, which are at times formed about the moon and sun, are of quite a different character from halos. In the first place, they are of a much smaller size. They are, for the most part, not more than four times the breadth of the luminary, away from its rim; their apparent diameters being comprised within a range of from two to four degrees. They are also distinguishable from the halos by a yet more definite mark. The order of the succession of colours is reversed. The red presents itself at the outer border of the circle, and the blue at the inner rim, which is the ruddy side in the halo. The corona in reality is the offspring of mist rather than of frost; it is generated by the aqueous vapour floating in the air between the sun or moon and the observer. It is of the same order of appearances as the coloured rings produced on the windows of carriages, bedewed with moisture, when bright lights are looked at through them. A similar circle of iridescence can, at any time, be artificially caused to present itself by contemplating the flame of a lamp or candle through a piece of plate-glass upon which the minute spherical spores of club-moss have been dusted, or by looking at the bulb of a mercurial thermometer shining brightly in the sun through a narrow slit cut in stiff paper by the point of a penknife.

The colours exhibited in the corona are of the same nature as the phenomena known to opticians as "diffraction fringes." They are caused by interferences set up amongst the constituent vibrations of the light-beams as they glance past the spherules of mist. They are physically allied to the iridescence produced upon pearl buttons by the striæ of their surface, or by lines traced very closely together upon glass by the diamond, and to the coloured bands which are often noticed upon windows soiled with smoke and dust.

Coronal rings are less frequently observed about the sun than they are about the moon. But this is only because they are more easily overlooked when they occur in the midst of the glare of bright sunshine than they are in soft moonlight. They may be very commonly detected in connection with the sun, if the eye is screened from the overpowering glare by darkly-coloured or smoked glass. At times two, or even three, circular bands may be seen surrounding each other, and the second and third circles are then at the same distance from each other, and from the first, that the first is from the sun. Professor Kaemtz has given an account of one very remarkable case in which as many as eight concentric circles were formed, the first three being blue, white, and red, and those which followed in the outward order of succession being purple, blue, green, yellow, and red, thus obviously constituting a second series, as the transition in the same direction was again from blue towards red. When a corona is visible round the sun, its colours are more brilliantly developed than they are in connection with the moon. The

head of the Spectre of the Brocken, which is merely the shadow of a human figure cast upon mist,* is sometimes surrounded with a circular glory of coloured light. This, in such circumstances, is simply the chromatic fringe developed by diffraction at the margin of the dark shadow. The so-called "Fog-image"† of the Rigi Kulm, and of other elevated parts of the Swiss mountains, is essentially of the same nature.

Halos invariably occur in some form of cirrus, which is properly the ice-cloud. The coronas, on the other hand, as commonly present themselves in the cumulus variety of cloud; but all clouds, excepting the ice-clouds, are capable of producing them, provided they are not too dense to permit the passage of red light. Lunar halos, as a rule, present themselves when the barometer is falling, and when the cirrus cloud is thickening into cirro stratus; they are, therefore, correctly regarded as harbingers of rain. The corona is not so much a weather sign in itself as the halo (Fig. 6), but it becomes so in the changes which it is liable to undergo after its first formation. The circle is of a less diameter when the mist-spherules are large than it is when they are small. The corona consequently contracts gradually in breadth as the deposition of moisture becomes more copious. A contracting corona hence indicates the approach of rain, whilst an enlarging corona, on the other hand, gives promise of fine weather. Coronas round the sun are, however, scarcely as significant of changes in the weather as those which appear about the moon, because they are liable to be produced in all kinds of clouds which are not too dense for the passage of the stronger vibrations of light.

* Cassell's Popular Science, Vol. II., p. 1.

† The "Nebenbild" of the German meteorologists.

FIG. 6.—HALO ROUND THE SUN.

THE HOUSE-FLY AND ITS PARTS.

A POINT of great interest in connection with the truly immense class of insects is the fact that the majority are endowed with wings. A few of the most primitive forms have never had any of these most useful appendages; others have, during the long course of their development, lost the means of flight, as shown to some extent by their close relationship to winged forms. Nevertheless, it is not to be wondered at that the structure of the wings has for long been made the basis of the scientific classification of insects.

True it is that, leaving on one side the wingless forms, such an arrangement is not absolutely satisfactory, and that the modifications, for instance, of the mouth parts, and the completeness of the changes gone through may be evidences of greater affinity, or the reverse, than likeness or difference in flying organs. Yet, for every-day purposes in the field, the old orders, arranged according to the wings, still to a great extent hold good.

This is pre-eminently true of the most characteristic one, which includes the common house-fly, which, we shall find, belongs to the order *Diptera*, or two-winged insects, the hinder pair of wings being converted into two little organs like drum-sticks, called *halteres*, or balancers (Fig. 17). If we examine any specimen under a magnifying glass we shall find that, like all other insects, its body is divided into three parts—the *head*, the *thorax* or breast, and the *abdomen* or belly—and each of these parts again consists of a certain number of rings or segments (Fig. 1). This division of the body into segments is the great distinguishing feature of many invertebrate animals. We noticed it in the earthworm, which consists of a number of similar rings following each other. Here, however, we find nothing like jointed limbs attached to the segments, but only a few very fine bristles with which the creature forces its way through the soil. The sea and sand worms are, however, more elaborately provided with fleshy tubercles and a whole armoury of bristly weapons. The higher forms of articulate animals, such as centipedes, spiders, crabs, lobsters, and insects, are distinguished from the lower by the possession of jointed legs, and all these creatures at present go to make up the various classes of the group *Arthropoda*.

It may well be asked, How is it possible to regard so complex a creature as a crab, a beetle, or a fly, as made up of a number of rings or segments? Indeed, on a superficial view it is difficult to realise that such is the case, and the difficulty arises from the fact that, while the ringed type of structure in all of them is fundamentally the same, the modifications which it undergoes in each segment are subject to endless diversity. Thus some of the rings may be enlarged to a comparatively enormous extent at the expense of those adjoining them. Some of them may be furnished with legs or wings, while others are destitute of these appendages, and two or more rings may be so welded together as to render their separate identification a matter of considerable difficulty. The more perfectly organised the body is—that is, the more the various actions and processes of life are carried out by organs *specially* adapted for their purpose—the more will its parts differ from one another, and the less uniformity of structure will it present. In the worm or the maggot of the very fly which forms the subject of this paper,

practically speaking each one of the similar segments of which the body is composed contributes a little to the act of locomotion, but, in the perfect insects,

FIG. I.—THE HOUSE-FLY.
h, head; t, thorax; a, abdomen.

locomotion is effected much more perfectly by means of organs (the wings and legs) specially fitted for that purpose and confined to one particular part of the body—namely, the "thorax." The fly is a more highly organised animal than the worm, the maggot, or even the centipede, and its parts differ from one another, and the complexity of its structure is increased in corresponding proportion.

Insects are usually said to be composed of thirteen segments—viz. one for the head, three for the thorax, and nine for the abdomen. Inasmuch as the various appendages of the head, the jaws, *antennæ*, etc., are believed to be the limbs of originally distinct segments, there is much reason for considering the head as really composed of five segments instead of one.

The antennæ of the fly are composed of six joints only. They lie in a hollow in the front of the head, and, unless looked at carefully with a microscope, it is probable that only the third and sixth joints will be discerned, the first, second, fourth, and fifth being very minute (Fig. 2). The third joint is covered all over with a great number of little sacs extending inward from the surface, and covered with a fine membrane. Some have supposed that this joint is an organ of hearing, others of touch, and others of smelling. It is possible that insects may possess senses of which we do not know, and of which, therefore, we cannot form an idea. The three last joints spring from near the base of the third, and not, as usual, from the end of it, and the sixth is furnished with a tuft of fine hairs.

Perhaps the most wonderful portion of the fly's structure is the mouth. The mouths of insects are of two kinds—the *mandibulate*, or biting mouth, of which we have an example in the cockroach, and the *suctorial* mouth, or that adapted for suction, and of the latter there are many different forms; but, whatever may be the form of the mouth, it always consists of the same parts differently modified, though it does not follow that they are always present in their full complement. The *mandibles* and *maxillæ*, which are so conspicuous in the mouth of the cockroach, are absent from that of the fly, or, if present, are at least so difficult to recognise that we shall not notice them here. The mouth, therefore, consists of the following parts only — viz. the *labrum*, the *labium*, and the *maxillary palpi*, which are visible under ordinary circumstances (Fig. 5). If, however, we watch the insect while feeding in the sugar-basin we shall see that these parts form collectively the terminal portion of a double-jointed or elbowed organ, of which the basal portion, known as the *pharynx* (Fig. 3), lies usually within the head, but can be extended at will. The terminal joint being then straightened upon it, the two together form what is called the *proboscis* —an organ, indeed, not quite so big as

FIG. 2.—A SINGLE ANTENNA OF FLY.
The figures indicate the joints.

that of the elephant, but quite as indispensable to its tiny possessor. As the

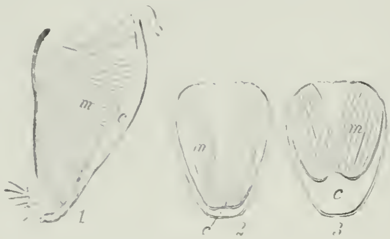


FIG. 3.—THE "PHARYNX," AN IMPORTANT PART OF THE PROBOSCIS.

1, "pharynx" in longitudinal section; 2, transverse section, muscles relaxed; 3, transverse section, muscles contracted. m, muscles; c, cavity.

mouth of the fly is of the suctorial kind, we shall find in the "pharynx" a most wonderful provision for causing the ascent of fluids from the mouth to the gullet, and so on to the stomach—in fact, it forms a very perfect pump. The greater part of it is filled with muscles, which, by their contraction, separate the walls of its cavity and thus cause a vacuum, into which the fluid aliment, moistened by the saliva, rushes. The muscles then relax and the pharynx closes upon its contents, which are thus passed on to the gullet.

The "labrum" (*lr*, Fig. 5) forms the covering of the mouth from above. It is a small lancet-shaped piece, and lies in a groove on the upper surface of the enormously enlarged "labium." It is provided at the base with two long processes, which lie on either side of the pharynx, and are connected thereto by muscles, by the action of which the proboscis can be straightened when in use.

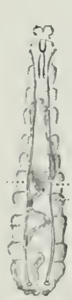


FIG. 4.—MAGGOT OF THE BLOW-FLY.

t, t, main tracheæ.

The "labium" is a very complicated and beautiful organ. It consists of the *mentum*—a horny piece on the under side of the base of the terminal joint, the upper surface of which is hollowed into a groove to receive the labrum. From the base of this groove springs the tongue, a very fine horny lancet, which thus lies between the labium and the labrum. The labium is terminated by two large fleshy lobes constituting the *ligula*, as in the cockroach, only here the lobes have become the most important and striking feature in the mouth. They are each traversed by a series of channels excavated in the soft membranous integument and converging to two larger ones of a similar character, which again open into the groove of the labium. All these channels,

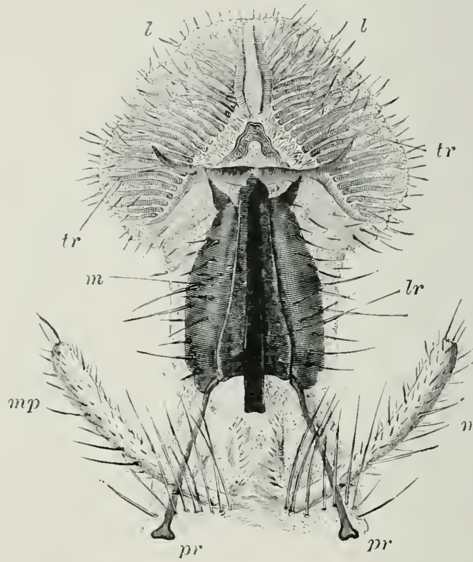


FIG. 5.—MOUTH OF THE BLOW-FLY.

lr, labrum; m, mentum; mp, mp, maxillary palpi; l, l, lobes; tr, tr, false tracheæ; pr, pr, processes of labrum.

which have received the name of *false tracheæ*, are kept open by a great number of horny rings—or, rather, half-rings (Fig. 7). In the blow-fly these half-rings are forked alternately at either end (Fig. 7, 2), thus making the proboscis a very beautiful microscopic object. The end of all this complicated arrangement appears to be to facilitate the flow of fluid substances by capillary attraction towards the mouth.

The *maxillary palpi* (*mp*, Fig. 5) are two club-shaped organs, springing from the

membranous integument of the pharynx. Although the maxillæ are not seen in this insect, they are found in some others, such as the gad-fly and the various kinds

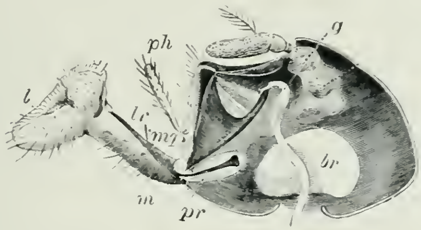


FIG. 6.—SECTION OF HEAD OF HOUSE-FLY.
ph, pharynx; g, gullet; br. brain: parts of the mouth as in Fig. 5.

of hoverer-flies, where they take the form of lancets, in common with the labrum and the tongue.

The eye of the fly is composed of a great number of similar parts, each of which serves the purpose of a separate eye, but it is doubtful whether the faculty of vision is so perfect as in man and in those animals where one highly finished organ supplies the place of all this multitude. Externally, the surface is divided into minute hexagonal areas, or facets, as they are called, about 2,000 to each eye, each of which is a double convex lens, the *cornea* of a separate eye, though sometimes the term cornea is applied collectively to the whole of them (Fig. 8). Each facet (Fig. 9) has behind it a conical body surrounded by dark pigments, the apex abutting on a fibre of the optic nerve. A very pretty experiment may be made by placing a flattened portion of the cornea of the eye on the stage of a microscope, and then holding a small object—such as the point of a knife—between the stage

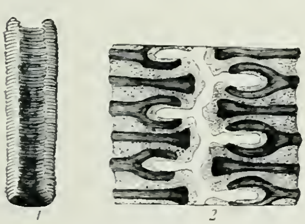


FIG. 7.—FALSE TRACHEÆ OF (1) HOUSE-FLY; (2) BLOW-FLY.

and the mirror, when the image of the object will by careful adjustment be visible in each of the facets.

We will now pass to the second division of the body—the thorax (Figs. 1 and 10), in which the organs of locomotion are concentrated. The three segments of which it consists are known by the following terms—viz. the *pro-thorax*, the *meso-thorax*, and the *meta-thorax*, which may be easily remembered as *fore*, *middle*, and *hind* thorax, such being the meaning of the Greek prefixes employed. Each bears a pair of legs, and, in addition, the "meso-thorax" carries the wings, and the "meta-thorax" the "halteres." In the cockroach it is easy to separate the three segments from each other: but in the fly this is much more difficult, for although we are sure, from the existence of the three pairs of legs, that three segments are concerned, yet it will be found that they are so merged together into one compact mass that, only by carefully comparing it with other insects, and by taking into account its internal muscular structure, are we able to know where one segment ends and another begins. It will suffice, therefore, here to state that, as the wings are the most important organs carried by the thorax, and require large muscles to effect their movements; the segment to which they belong—viz. the meso-thorax—is greatly enlarged at the expense of the other two, almost the whole of the parts shown in the accompanying drawing of the thorax (Fig. 10) belonging to it. By a universal law of growth the enlargement of any one segment is always accompanied by a corresponding diminution in those adjoining

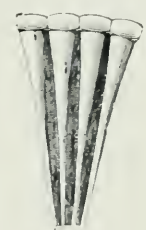


FIG. 8.—CORNEA AND CONES OF HOUSE-FLY IN SECTION.

FIG. 9.—FACETS OF THE FLY'S EYE.

it; thus the pro-thorax is reduced to a mere rim in front, to which the fore-legs are attached, and of the meta-thorax scarcely anything remains but its append-

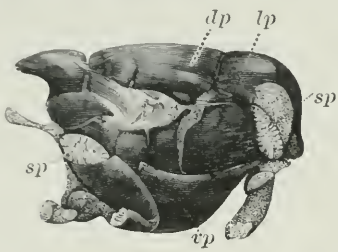


FIG. 10.—SIDE VIEW OF THORAX OF BLOW-FLY.

dp, dorsal plate; lp, lateral plate; vp, ventral plate; sp, sp, spiracles.

ages—the halteres and the hind-legs. In the meso-thorax of the fly may be seen all the parts of which an insect segment can consist — viz. a *dorsal plate* on the upper surface, a *ventral plate* on the lower surface, and two lateral or *side-plates;* also two pairs of appendages—an upper pair (the wings) and a lower pair (the legs) (Fig. 11). The dorsal plate covers the whole surface of the back between the wings. The ventral and lateral pieces are scarcely less conspicuous. The former occurs between the fore and middle legs. In the pro-thorax the upper pair of appendages are wanting in the perfect insect, but exist as two button-shaped bosses on the back of the pupa. In the meta-thorax the upper pair of appendages are found in the halteres, which are a kind of modified wing. Some have thought that they serve to balance the insect during flight, like an acrobat's pole. It is probable, however, that they serve some other purpose besides, and are organs of sense, for peculiar microscopic structures are found at their base, to each of which one of the largest nerves in the body proceeds.

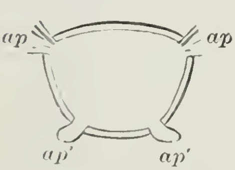


FIG. 11.—SECTION OF AN INSECT SEGMENT.

ap, ap, superior, ap', ap', inferior appendages

The wings, like those of other insects, consist of a double membrane; they are in principle flattened bags or sacs, extensions of the skin of the thorax; they are strengthened by folds of the membrane called *nervures*, in which ramifications of the *tracheæ* or breathing tubes run. Both surfaces are covered with very minute hairs.

The legs consist of the same parts as in the cockroach. The joints are five in number, and the last is furnished, in addition to the two claws which are found in all insects, with a delicate pad (Fig. 12) by means of which the fly is enabled to walk upon walls, ceilings, and so forth. The pad is furnished on its under surface with a great number of trumpet-shaped hairs (Fig. 12), from the ends of which a viscid fluid is secreted, which causes the feet to adhere sufficiently to any surface to bear the insect's weight.

FIG. 12.—FOOT OF HOUSE-FLY.

p, p, pads; a, hairs of pad; c, c, claws.

Flies are frequently attacked by a kind of mould, called *Empusa Muscæ*, which eventually kills them; but before this happens they are rendered so weak that they cannot exert sufficient muscular force to detach their feet from the surface on which they rest. In the autumn dead flies may frequently be seen thus fixed on windows, with the still spreading fungus forming a whitish patch around their bodies.

The rings of the abdomen are, as before stated, nine in number. Of these the first five are very simple, consisting only of a dorsal and a ventral plate, with no appendages. It is in this portion of the body that the articulated structure is more easily seen. The dorsal plates are much larger than the ventral (Fig. 10), and occupy at least three-fourths of the circumference of each segment, the small

ventral plates occupying a narrow space in the centre of the under surface. The four last segments contain the reproductive organs.

Before we leave the external parts of the insect we must look at the *spiracles* (Figs. 13, 14, and 15), of which the most conspicuous are those of the thorax. They belong to the hinder portion of each segment, and there are two pairs of them, one belonging to the prothorax in front, and one to the meso-thorax behind. The meta-thorax has no spiracle. They are furnished with branching processes, projecting across the opening for the purpose of keeping out dust. The spiracles of the abdomen (Fig. 13) are situated near the lower edges of the dorsal plates, and are very small, requiring a microscope to reveal them; they are little round pores with a few hairs projecting across them. The main tracheæ of the thorax extend from the anterior to the posterior spiracle on each side, and branch out in all directions between the great muscles, which occupy this part of the body, as may be seen from Fig. 18. From these a large branch passes into the head and another into the abdomen, at the base of which it swells out into two large sacs filled with air. The abdomen of the drone fly is frequently rendered almost translucent by the presence of these large air sacs.

FIG. 13.—ABDOMINAL SPIRACLE.

FIG. 14.—PRO-THORAC SPIRACLE.

The nervous system of the fly consists of a series of *ganglia* connected by nerve cords. This type of structure is, however, greatly modified in the fly; the ganglia, which in most other insects are repeated at each segment, are here concentrated into two chief nerve centres, one in the head and one in the thorax. That in the head—which may be called the "brain" (*br*, Fig. 6)—surrounds the gullet and send nerves to the eyes, antennæ, and mouth. The nerves of the eyes are very large, and are called the optic nerves. A filament from them enters each of the cones of the eye. The nerve centre of the thorax supplies the muscles of this part of the body—a large branch goes to the halteres, and a long branching filament to the various organs of the abdomen. If a fly be preserved in spirits it will render the nerves hard, white, and easily traced.

The alimentary canal (Fig. 16) commences with the pharynx, and passing

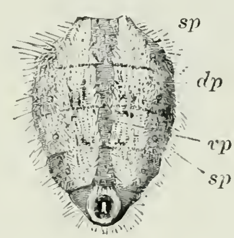


FIG. 15.—UNDER SURFACE OF ABDOMEN OF HOUSE-FLY.

sp, sp, spiracles; dorsal and ventral plates as before.

through the "brain" enters the thorax, this portion forming the gullet. It then divides into two branches, one of which is continued as a fine tube into the abdomen, where it opens into a double sac, the crop. Into this the food first passes, and, after remaining for a time, is brought up again, and in order to undergo digestion passes into the other branch. The latter opens at once into the *gizzard*, a globular cavity with thick walls, which secretes the gastric juice. As the fly feeds upon fluid substances this organ is not provided with teeth. The gizzard is followed by the stomach or *ventriculus*, which occupies the whole length of the thorax, its surface divided into little square pits by the longitudinal and

circular muscular fibres which surround it. The small intestine, or *ileum*, extends from the stomach to the opening of the bile tubes (or *Malpighian glands*), which are

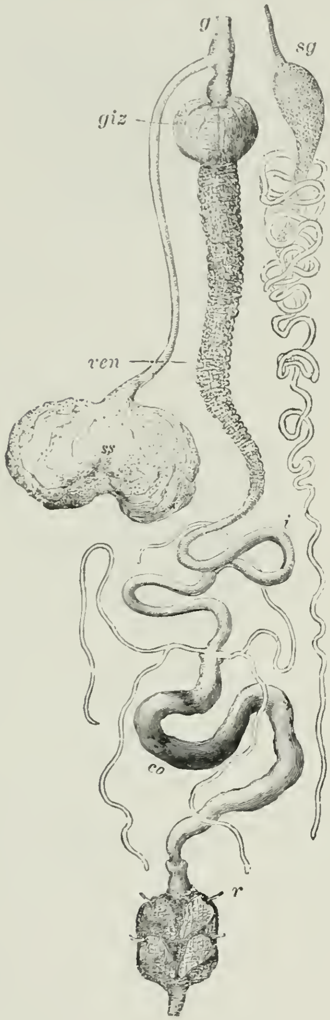


FIG. 16.—ALIMENTARY CANAL.

g, gullet; giz, gizzard; ven, ventriculus; sg, salivary gland; i, ileum; co, colon; r, rectum; ss, crop.

succeeded by the large intestine, or *colon*, and the *rectum*. The salivary glands commence in the thorax as long, narrow tubes, one on each side of the stomach, but their blind extremities extend into the abdomen. Each tube opens into a little sac which communicates by a ringed duct with the base of the tongue. Their office is to secrete the acrid saliva. It is this which is poured into the wound and imparts its painful character to the bite of gnats and other insects. The bile tubes are long, beaded tubes which unite together in pairs, to empty themselves by two large ducts into the intestine. A difference of opinion exists as to whether they answer to the liver or the kidneys of the higher animals.

FIG. 17.—BALANCER OR "HALTERE" OF FLY.

The muscles of the fly are attached to the inner surface of the horny integument, which thus answers the purpose of a skeleton. They differ from those of the higher animals chiefly in the fact that they are—at least many of them—attached directly to the integument at either end without the intervention of tendons, so that they are of equal diameter throughout. Like the nerves, they are rendered hard and white by the action of spirit. We shall have space only to notice the most important, which are those of the thorax (Figs. 18 and 19). This part of the body—with the exception of the

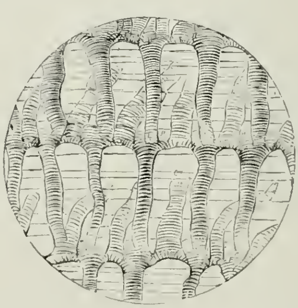


FIG. 18.—TRACHEÆ RUNNING THROUGH MUSCLES OF THORAX.

narrow passage left for the stomach and salivary glands—is entirely filled with muscles. The two principal masses occur just under the dorsal plate, and extend longitudinally from end to end of the

thorax. On each side of these, and separated from them by the main tracheæ,

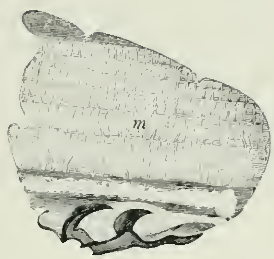


FIG. 19.—SECTION OF THORAX OF BLOW-FLY.

m, longitudinal muscles of flight.

are other muscles, which take a different direction, passing from the dorsal to the ventral surface. By the action of these two sets of muscles, alterations are produced in the shape of the thorax, resulting in the alternate elevation and depression of the wings during flight. These alterations and the consequent movements of the wings may be produced artificially by taking a recently killed fly and placing one blade of a pair of dissecting forceps behind and the other in front of the upper part of the thorax, and alternately compressing and relaxing the forceps, when the wings will be seen to open and close as they do during flight.

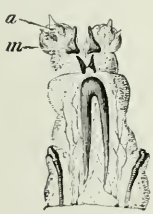


FIG. 20. — HEAD OF MAGGOT OF BLOW-FLY.

a, antenna; m, mandible.

As in all other insects, there are no blood-vessels in the fly, and the heart is represented by a slender pulsating tube called the *dorsal vessel.*

FIG. 21.—SPIRACLE OF LARVA OF BLOW-FLY.

The larva or maggot of the fly (Fig. 20) is found in dung, but, as that of the blow-fly found on meat is so much better known, we will conclude with a few words on it: the description of the one will apply pretty well to the other. The body consists of thirteen segments, and is unprovided with feet, its movements being effected by the contraction of one segment upon another, aided by a pair of minute hooklets, the *mandibles,* with which it tears its way through the putrefying mass in which it lives. Eyes there are none, for they are not required. A pair of fleshy globular organs, well supplied with nerve cells, may represent the antennæ. The alimentary canal is somewhat similar to that already described in the fly, except that the crop opens by a short neck into the gullet, instead of being connected thereto by a

FIG. 22.—PUPA OF BLOW-FLY.

long tube, as in the fly. Two long silvery tubes, the main tracheæ, extend nearly the whole length of the body, and open by spiracles (Fig. 21) in the last segment. When the time arrives for the insect to undergo its metamorphosis, the skin of the larva dies, turns first red and then almost black, and hardens into a barrel-shaped protective covering for the insect called the pupa case (Fig. 23). Within this a great change takes place, all the muscles and tissues of the maggot disappear—with the exception of the nerve centres—and are resolved into a semi-fluid matter, from which those of the fly are formed anew within a delicate integument called the pupa skin. The pupa case or dead skin of the larva thus serves the same purpose as the silken cocoon spun by the silkworm,

FIG. 23. — PUPA CASE.

only the maggot has not the trouble of spinning it, and the enclosed pupa skin answers to the skin of the silkworm pupa (or chrysalis, as it is sometimes called) when it is removed from the cocoon. The legs and wings of the future insect are each enclosed in a separate prolongation of the pupa skin (Fig. 22), which remains behind as a delicate membrane in the pupa case after the escape of the insect from its prison. So great is the change that it is almost difficult to conceive that the maggot and the fly are one and the same being.

PHOTOGRAPHY IN COLOURS.

By T. C. HEPWORTH.

THERE is a widely spread belief that the camera gives absolutely truthful results, and that, while the painter is liable to make grievous mistakes, the photographic plate cannot err. This, we shall see, is certainly not the case if we consider the manner in which an ordinary photograph translates colour into monochrome. Let us first refer to the work of an engraver, whose business it is to accomplish the same thing.* A painting, rich with all the pigments possible to an artist's palette, is given to him, with instructions that he is to express all those colours in black and white. This he does by cutting lines of various thicknesses and distances from one another in the material which he is employing, be it steel, copper, or wood. White he will represent by an entire absence of line ; yellow, being next in luminosity to white, he will indicate by narrow lines wide apart ; blue by closer and thicker lines ; red by still thicker and closer lines, until he comes to black, in which the lines touch one another.

But suppose that a photographer, with the means at his disposal only a few years back, were given the same painting with the same instructions which the engraver received. He would have no control over the action of the lens and chemicals in his hands, but must leave both to do the work in their own way, and the result would quickly show that that way was not to be commended. The blue sky would come out white, and the clouds upon it, being white also, would become invisible in the photographic copy of the picture. The yellows, instead of being bright and prominent in tone, would be almost black. The brilliant reds would be still blacker, while the greens of grass and trees would also be funereal in hue. Instead of a faithful picture, we should get one in which the colours were all falsified. The same falsification is not so apparent in a photograph taken direct from nature, because every colour in a landscape is so mingled with white light that the sensitive plate gets more reflected luminosity from coloured surfaces than it might otherwise expect to receive.

This faulty representation of colour by the photographic plate, as commonly employed until quite lately, has long been manifest to those who have no knowledge of the cause, for it becomes evident in ordinary portraiture. A blue dress comes out in the photograph white, a yellow dress or a red one black. Auburn hair, instead of being bright as burnished gold, is as the plumage of the raven, and it has been a common expedient among photographers to powder such hair white before taking the photograph, in order to compensate for the inevitable darkening. The same thing happens with coloured flowers—yellow daffodils, for example, losing all their beauty and looking as if stained with ink. Under the same treatment an autumn landscape—rich with its splendid foliage, tints of red, orange, russet, and brown—loses its beauty, and the trees become dead and lifeless.

It will simplify matters if we photograph an object which comprises all colours, and note the effect obtained. The solar spectrum, obtained by breaking up white light into its constituent coloured rays by means of a prism, offers us the

* *See* "Colour Printing," CASSELL'S POPULAR SCIENCE, Vol. I., p. 32.

purest tints it is possible to secure. A diagram of it is shown in Fig. 1, the colours being indicated in their proper places, while the initial letters above by a skilled engraver, but unfortunately it does not do so. A photograph of the spectrum taken by means of the ordinary dry plate will show that the greatest

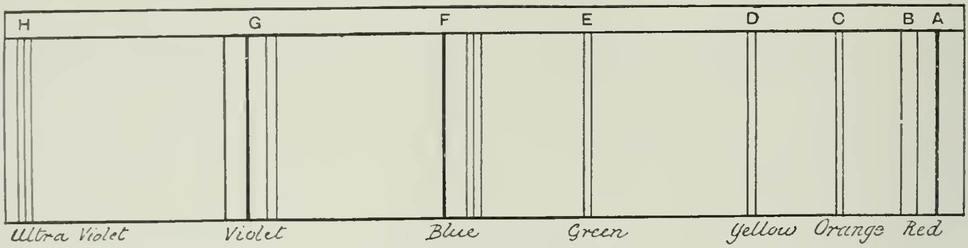


FIG. 1.—WHITE LIGHT BROKEN UP INTO ITS CONSTITUENT RAYS.

refer to the Fraunhofer lines. At Fig. 2 is shown the apparent brightness of the various parts of the spectrum as they appear to the normal human eye. action has taken place, not in yellow, but in the violet region of the coloured ribbon of light (Fig. 3); that its activity is carried far into the ultra-violet

FIG. 2.—SOLAR SPECTRUM AS SEEN BY THE HUMAN EYE.
Compare with Figs. 1 and 3.

The brightest part of the spectrum as seen by the eye is the yellow region marked by the double line D, the luminosity rapidly decreasing as we look to- region which is invisible to the eye, and photographic action is feeble when we come to the yellow, orange, and red portions of the spectrum. We thus see

FIG. 3.—THE EFFECT OF THE COLOURED RAYS UPON A PHOTOGRAPHIC PLATE.
Note that the action of the light is most marked at the violet end of the spectrum, i.e. on the left hand side of the figure.

wards the red end at one side, or at the violet end at the other side. If our ordinary photographic plate saw the spectrum in the same manner, there would be no difficulty about giving to the colours the same values as that accorded to them why, when we photograph a blue vase containing red and yellow flowers, the vase comes out white and the petals of the flowers black.

But although the photographic action is, as stated, feeble in the yellow and red

portions of the spectrum, it is not entirely inert, and we may take it as certain that an ordinary photographic plate is sensitive to all portions of the spectrum, provided that sufficient time be allowed for certain colour rays to assert their individuality. For this reason there is no dark-roomlamp which is absolutely safe. and the writers of the text-books are careful in impressing upon their readers the necessity for keeping plates while under development covered as much as possible.

FIG. 4.—FRUIT STUDY: A NON-CORRECTED PHOTO.
Compare with Fig. 5.

FIG. 5.—FRUIT STUDY: A COLOUR-CORRECTED PLATE.
Compare with Fig. 4.

As a proof of what has just been said, the writer has taken a photograph of an oil portrait which is sufficiently old—it was exhibited at the Royal Academy in 1840—to have become mellowed in tone. The flesh tints are yellow, the model is arranged in a red velvet dress, and her light brown hair is adorned at one side with a red rose. The picture, in fact, is painted in what an artist would term "warm tones"—there occur in it no blues, violets, or whites. It was photographed in a good light with an ample exposure, and the result was an extremely true rendering of the original. Yet the plate used was not an *orthochromatic* one, and no light filter was employed. In other words, there were no blues to tone down by a screen, and there was no particular need to give increased sensitiveness to the yellows and reds by the employment of a special plate. This photograph illustrates a point which is often lost sight of.

About thirty years ago Professor Vogel made the important discovery that, by incorporating with the gelatine emulsion which forms the sensitive surface of the modern photographic dry plate certain dyes, the sensitiveness of the plate to green and red became much increased. Plates so prepared are known as *orthochromatic* plates, and can now be obtained of all dealers. They are used in conjunction with a coloured screen placed over the lens, which has the effect of reducing the intensity of the blue and violet rays. By this means the difficulty with regard to rendering colours in their true tone relation to one another has been obviated, and we are now able to present pictures of coloured objects in monochrome which are at least as true to the originals as is the work of the skilled engraver. The improvement is of the greatest value, and such plates and screens are imperatively necessary in copying paintings and coloured objects generally. That photographers are beginning to see the advantage of their use is indicated by the fact that, whereas a few years ago they were only obtainable commercially from one or two sources, they are now made and largely advertised by all plate and film manufacturers. They certainly require extra care in handling in the dark room, being far more sensitive to the light from the red lamp than are ordinary plates, and this circumstance has undoubtedly prejudiced many against their employment.

There is nothing more beautiful than the picture of a well-lighted summer landscape as seen on the ground-glass focussing screen of the photographic camera. The form of every object is perfectly drawn, the very ripples in the water are seen to move, the various shades of the picture are faithfully reproduced, and, best of all, the whole scene is bathed in a wealth of colour. It was known, even before the commencement of the Christian era, that an image of this kind could be formed by the action of light through a small orifice, and we can have no doubt that one of the first uses of the lens was to fit it to such an arrangement. This so-called "camera obscura" has been in use for centuries, and we may be quite sure that it was the fond dream of many an observer to make the lovely chromatic image formed by such means a thing of permanency rather than a mere optical illusion. The first experiments in photographic chemistry were tried with that object in view.

The daguerreotype method of producing pictures had not been brought forward more than a few years when, in the first photographic newspaper ever published (*The Daguerrean Journal*, New York), appeared the following announcement: "New and valuable discovery of the Hillotype, a process of producing impressions upon metallic plates with all the colours of nature." The inventor was the Rev. L. L. Hill, hence the name of the process. The alleged discovery made an enormous sensation at the time in the United States, and afterwards in Europe. Mr. Hill kept the process secret, but he showed many specimens, which evoked the admiration of well-known men—Morse, of electrical fame, among the number—who testified to their belief that a great and important discovery had been made. It was a thing that everyone had been looking for, and hoping for, ever since a camera picture had been possible—the one thing needful to give photography its crowning triumph.

The Rev. Mr. Hill next announced that he would publish a book giving all details of his colour process, and the subscriptions which he secured in advance totalled up to many thousands of dollars. The book appeared, and contained a number of impossible formulæ, of which no one could make either head or tail. Then the author disappeared from public view,

and doubtless lived for many years on his ill-gotten gains. The pictures which he showed were skilfully coloured by hand, either with powdered pigments or with pigments mixed with alcohol.

The Hillotype process is the prototype of many frauds of the same kind, and many credulous persons have to deplore loss of capital by having invested money in schemes quite as fallacious. Every few years the announcement comes that somebody has at last discovered the great secret. Perhaps matters go as far as the issue of the prospectus of a company formed to work the process, and then nothing more is heard of it.

At the same time, men of ability and scientific attainments have not left this interesting field of exploration entirely to the company promoter. We have seen how, in the production of orthochromatic plates and colour filters, a great advance has been made in making a photograph show the same luminosity of the solar spectrum which the eye sees; and although this does not give us a coloured picture, it helps us towards arriving at that goal. We will pass over the early experiments of Becquerel, the labours of Lippmann and others, as being of merely scientific interest, and helping little towards the practical solution of the colour problem.

Mr. F. E. Ives, of Philadelphia, has the distinction of being the first to produce an instrument which exhibited photographs in stereoscopic relief and also invested with the charm of colour. This instrument he called the "photo-chromoscope"—which title was subsequently shortened to "kromskop." A photograph of it is shown at Fig. 6. In the paper on "Colour Printing" it is shown how, by using colour filters, or screens, it is possible to obtain three negatives of any coloured object. This procedure is based upon the Young-Helmholtz theory, which assumes that there are three colour sensations—possibly governed by three sets of nerves in the human eye—and that all the colours which we see are compounds of the three—namely, red, green, and blue-violet.

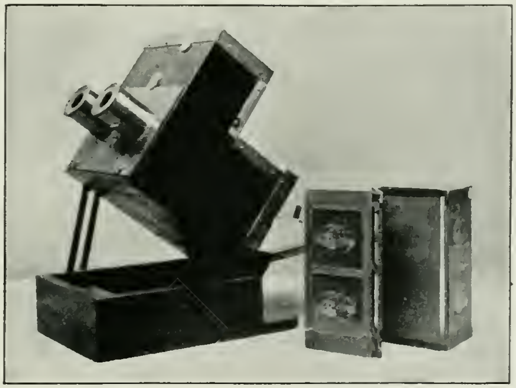


FIG. 6.—THE IVES "KROMSKOP."

This is the first instrument which showed a photograph in natural colours. Three negatives are taken, each negative being protected by its own colour filter.

By Ives's system three negatives are produced, each being taken in the camera through its particular colour filter. (Each negative is in reality a double one, so as to secure stereoscopic relief, the instrument being a binocular one.) From these negatives "positives" on glass are printed, and these positives are placed in the instrument in association with coloured glasses. Each positive is illuminated by the complementary tint to that of the filter under which the original negative was taken. The three images and their three colours are, upon looking through the eye-piece of the instrument, mingled upon the retina, and the result is a most beautiful optical illusion—a single image in perfect relief and brilliant colour. Nothing more perfect has ever been seen than the results given by the kromskop; but the instrument was

necessarily of delicate construction, and it has not come into common use.

Mr. Ives also introduced a projection instrument by which triple photographs

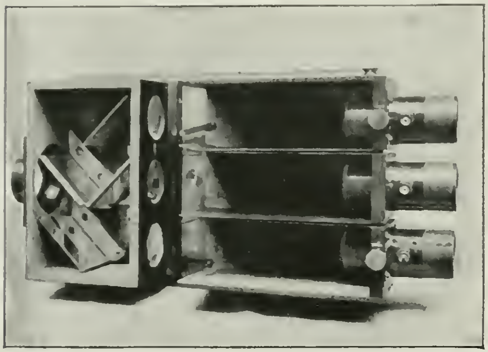


FIG. 7.—IVES'S TRIPLE LANTERN FOR THROWING COLOURED PICTURES UPON THE SCREEN.

Three figures are thrown upon the sheet, and these are made to approach and finally to overlap each other. The result is a beautifully coloured picture.

obtained in the same manner—except that they were not stereoscopic—could be shown on the lantern screen (Fig. 7). Unfortunately, the coloured glasses employed, and the necessary reflections from them, involved such a loss of light that even with a powerful electric arc a disc of only four feet in diameter could be effectively illuminated. As will be seen by the photograph, three lenses, and therefore three discs, were projected on the sheet. Each of these was of a different fundamental colour, and they could be shown either separately or combined. It was very pleasing to see the three discs, at first separate and distinct, made to approach and cover one another, thus forming a picture invested with the colours of nature.

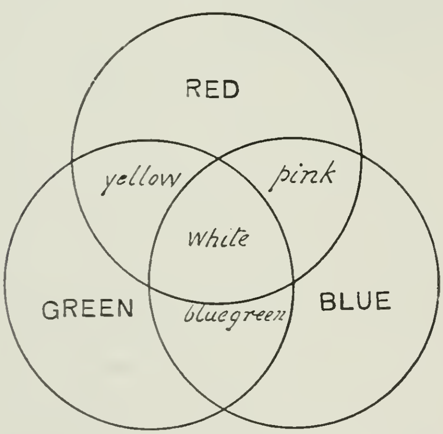


FIG. 8.—DIAGRAM OF THE THREE OVERLAPPING DISCS: WITH COLOURED LIGHTS.

Here the combination of the red, blue, and green produces white. Compare with Fig. 9, where the pigments are dealt with.

To Mr. Ives certainly belongs the credit of laying the foundation of natural colour photography, and those who have most successfully followed in his footsteps are

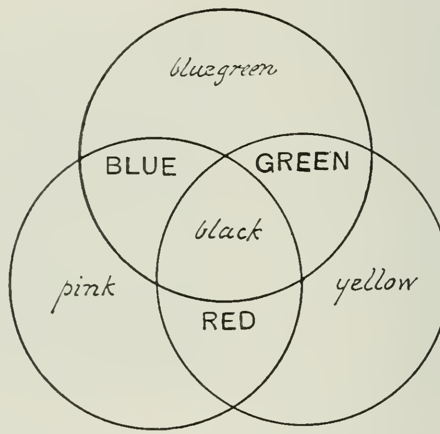


FIG. 9.—DIAGRAM OF THE THREE OVERLAPPING DISCS: WITH PIGMENTS.

Notice that the combination of the three produces black. Compare with Fig. 8.

the first to acknowledge the debt which they owe to him.

If, in using a tri-colour lantern of the pattern shown in Fig. 7, we cause the three coloured discs to overlap one another upon the screen, we produce white light, just in the same way as white light is produced by remingling the various coloured rays separated by the prism in Newton's original experiment.

In Fig. 8 the three overlapping discs of colour are shown diagrammatically, and we also see in this same diagram how the red and green light combine to form yellow, the red and blue pink, and the green and blue blue-green. In this case

we are mingling coloured lights. But when we are dealing with pigments the case is different. If, for example, we paint upon a white card a disc of red, we cause part of the white light previously reflected to the eye to be absorbed—namely, the green and blue rays. When we have painted it the card appears darker, because only a portion of the light is received by the eye.

In Fig. 9 we see the result of overlapping discs of gelatine which have been stained with the complementary colours to red, green, and blue, and we find that where they mingle at the centre of the diagram they produce black. To put the matter shortly, in the one case we are dealing with coloured lights, and in the other with coloured shadows. These diagrams will help us to understand why, in practising the tri-chromatic method of photography, the positive from a particular filter negative must be printed in the complementary colour of that filter—that from the red filter negative in pink, and that from the blue filter negative in yellow.

Another investigator who has materially helped towards the solution of the problem is Sir William Abney, who by means of the colour *sensitometer* which he devised has made the manufacture of light filters so certain that their commercial introduction has become possible. Before the invention of this instrument each investigator had to find out by tedious trials of many differently coloured filters the particular tints that would cut down the right proportion of the green, blue, and violet rays so as to secure upon the photographic plate densities agreeing with nature. Nor must the name of Mr. James Cadett be omitted from the list of benefactors, for he has in his "spectrum plate" produced a photographic surface which is sensitive to the whole range of the spectrum.

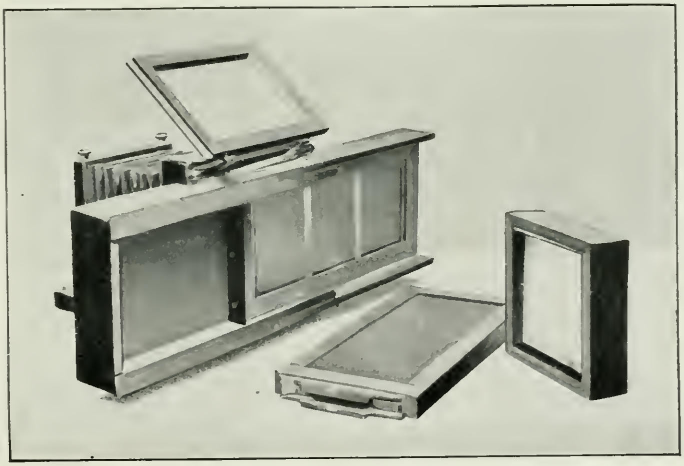


FIG. 10.—SLIDING BACK WITH THE THREE COLOUR FILTERS

Profiting by the labours of these workers, and bringing to bear upon the matter much original thought, Mr. Sanger Shepherd has of late years worked out a system of producing coloured transparencies for the lantern of very fine quality, far transcending in their effects the carefully hand-painted slides which were at one time in vogue, and which were most costly to buy. By first considering the apparatus which Mr. Sanger Shepherd has devised for carrying out the production of these coloured

pictures we shall be better able to understand the details of the work.

Fig. 10 represents an ordinary camera, with its focussing screen thrown back, and in place of the usual dark slide a set

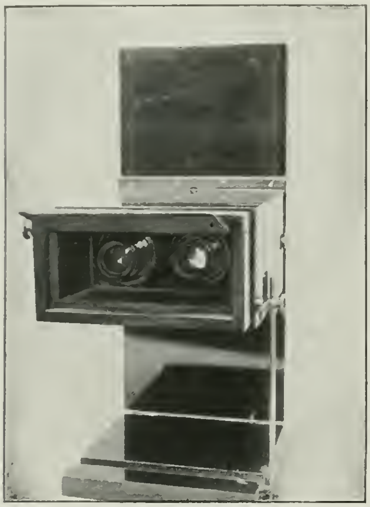


FIG. 11.—A STEREOSCOPIC CAMERA FOR THREE-COLOUR NEGATIVES.

of colour filters, consisting respectively of red, green, and blue glasses. Just below these three windows is seen lying on the table a repeating back, containing a plate long enough to cover all three filters. This back is placed behind, and slides with the colour filters in the groove provided for them. The first exposure through the red filter is made for the requisite number of seconds. The lens is then capped, and the back and coloured glasses are pushed forward until the green occupies a central position, after which another movement brings the blue filter under the action of the lens. A separate focussing screen is used in this work, and is shown on the right-hand side of the picture.

The negatives—each one, of course, different, for in each only certain coloured rays from the original object have been allowed to pass the filter—are now developed, fixed, and dried like ordinary photographic negatives, and are then ready for the next operation—the production of the positive transparencies. These positive images are printed on a special form of film, consisting of celluloid coated with a chromate salt in gelatine. Gelatine so treated becomes insoluble in warm water after it has been exposed to light—a property upon which the well-known carbon process of photography depends. The film is placed upon the negative—image side outwards—and exposed to daylight until all details are visible in a brownish yellow tint, the picture at this period looking very like an undeveloped platinum print. The film is now immersed in warm water, the unaltered gelatine dissolves away, leaving a white image firmly attached to the celluloid, a picture in low relief in clear gelatine. The three pictures are now cut apart from one another, each to be stained a different colour.

Mr. Shepherd, however, considers that a better effect is obtained by making the print from the red filter negative upon an ordinary "Cadett" black tone lantern plate, and converting the black silver image into transparent greenish blue by treatment with a chemical solution which is supplied for the purpose. Adopting this modification, we may suppose that we have thus obtained a satisfactory blue image on glass. This will form the basis of a lantern slide. The print from the green filter negative is now stained pink, and that from the blue-violet filter negative yellow. These stains are made from carefully selected aniline dyes. The two pictures on celluloid are now attached to the lantern slide, the surfaces being brought into optical contact by means of Canada balsam, care being taken that the three pictures correctly register; the addition of a cover glass completes the lantern slide. Such slides are now highly valued by both scientific demonstrators and by artists, and are coming into general use.

Many attempts have been made to secure the same effects on a paper support as are possible in these beautiful lantern slides, but until quite lately these attempts have proved abortive. A ridiculous accident led to the discovery of a practical method of producing a coloured picture on paper—a picture which can be framed or preserved in an album. One of the stained positive films, fresh from its bath of dye, was carelessly laid upon a piece of blotting paper, and after a time, when the film was raised, it was found that the image which it bore—or, rather, the colour from that image—had been transferred to the paper. Here was the solution of the problem. After many careful experiments, Mr. Shepherd succeeded in devising out of this accidental circumstance a practical process, particulars of which he has now published. It may be said to begin where the lantern slide process leaves off.

Having obtained the three prints on the celluloid base, the same are separated and stained in their respective dye baths, as already detailed. We will now take the one bearing the red stain, and place it in a vessel of water, together with a piece of paper which has been coated with soft gelatine. The two surfaces are brought into contact in the water, lifted out, and squeegeed together. After resting for, say, fifteen minutes, the surfaces are separated, when it will be found that the whole of the colour has left the hard surface of the gelatine relief and has transferred itself to the paper. On this red image the yellow one is superposed in the same way, and when that is dry the blue is similarly placed in position. Of course, care must be taken that each image in turn is brought into correct register; but in practice there is no difficulty about this. The image on the celluloid is of such a hard and lasting nature that any number of prints can be taken from it, provided only that it receives a fresh charge of dye from its bath every time. This, briefly, is the latest method of producing a photograph in natural colours.

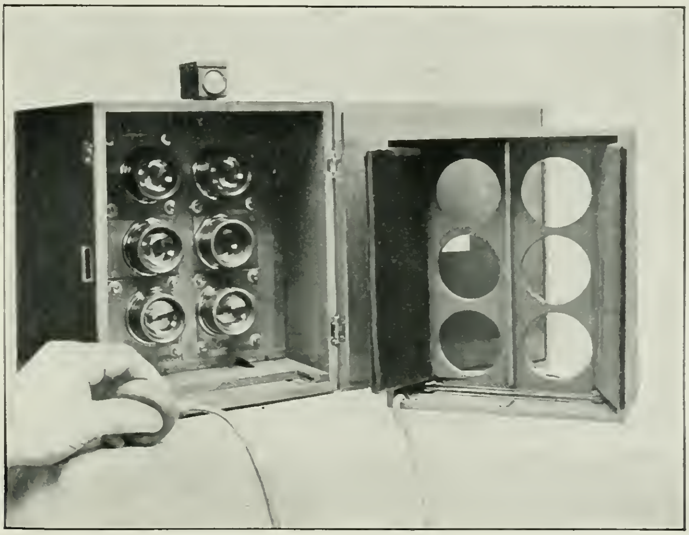


FIG. 12.—IMPROVED STEREOSCOPIC CAMERA WITH SIX LENSES.
Three double negatives are taken simultaneously.

Fig. 11 shows the form of camera devised for taking stereoscopic pictures for three-colour negatives, the filters and plate

sliding at the back vertically instead of horizontally, as in the camera already described. Fig. 12 is also intended for stereoscopic work, but in this case there are six lenses, so that the three double pictures can be taken simultaneously. The act of squeezing the pneumatic ball, as shown in the picture, results in the sudden opening and closing of two vertically placed shutters in the frame shown on the right, which frame, when in actual use, covers the space in front of the lenses.

For " instantaneous pictures " this particular form of camera has been recommended, for it is obvious that an instrument in which three separate exposures are necessary is of no use for the portrayal of moving objects. In the case of a moving boat, for instance, the vessel would occupy a different place in each picture.

The introduction of the colour filters must naturally reduce the rapidity with which a photograph can be obtained. With a good modern lens and plate it is possible to obtain a picture, in good light, in the one-thousandth part of a second. With the camera just described it has been found possible to obtain a picture of a breaking wave, under the Sanger Shepherd conditions, in the one-sixteenth of a second. This is a great advance upon anything which has previously been done.

The most recent form of camera for producing pictures in colour is shown at Fig. 13. This is also the design of Mr. Sanger Shepherd. It employs only one lens, but the three negatives are taken simultaneously on three separate plates. The ground-glass focussing screen is shown occupying the place of one of these, and the tops of the others are plainly visible peeping above the covering board of the instrument. If we remove this cover, as shown in Fig. 14, we shall see how the one lens is able to affect all three plates. By a system of mirrors the light is diverted into different paths, and each plate receives the amount it requires through its particular colour filter. It is simply a repetition of the means employed by Mr. Ives in his kromskop and projection lantern. By use of this ingenious instrument the photographer has no need to calculate so many seconds' exposure for each colour filter; this is done already for him. All he has to do is to uncap the lens for a given time, as is customary with the simplest form of

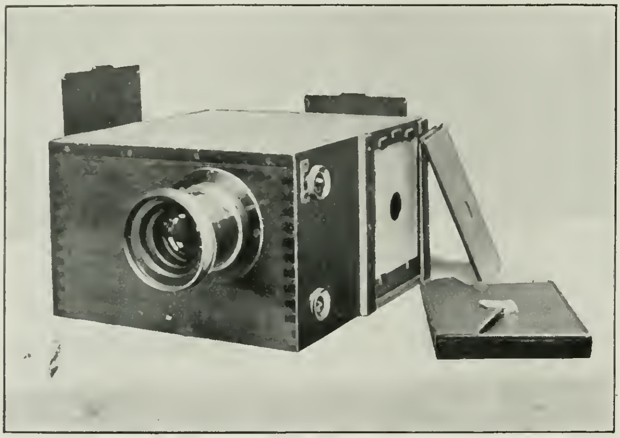


FIG. 13.—THE SANGER SHEPHERD CAMERA.
This has only one lens, but three negatives are taken simultaneously.

ordinary camera, that time being indicated by an *actinometer* or, what is perhaps better still, by practical experience.

By way of conclusion, we may say that photography in natural colours is now possible if we will meet Nature halfway, and give her certain dyes or pigments with which to play. By the automatic action of the light rays she will distribute these colours over the picture at the same time that the image is formed by the lens. But, while this method of producing a picture is a great advance, it does not reach the ideal of those who have hoped to see coloured images taken in a camera direct from nature. Probably this ideal will never be attained.

(For complete treatment of the whole subject of photography *see* "The Book of Photography," edited by P. N. Hasluck.)

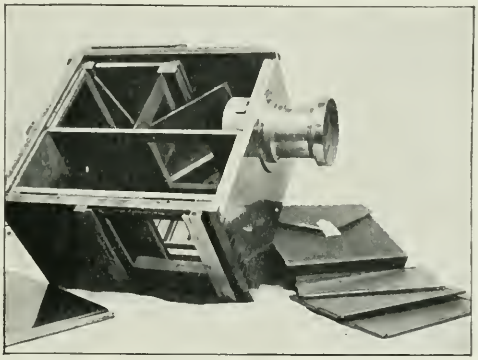


FIG. 14.—INTERIOR OF THE SANGER SHEPHERD CAMERA.

The light rays reach the three sensitive plates by means of a series of mirrors and reflectors.

THE MOVEMENTS OF PLANTS.

By ALEXANDER S. GALT.

WHAT is the difference between a plant and an animal? I remember hearing the question put by a teacher to a class of boys between ten and eleven years of age. One bright-faced youngster attempted to solve the problem by saying:

"A plant can't move, and an animal can."

Of course, it is easy to say, in the light of our fuller knowledge, that the boy was wrong, and yet he voiced in his direct, boyish fashion an idea that many adults have had for years. Let us put the question to the boy's father—theoretically, of course—and we shall very probably get something of the same sort of reply. We have so long been accustomed to look upon a plant as one thing, and an animal as quite a different thing. Now I do not propose to waste space by trying to elaborate the many points of difference between an ox and an oak tree; they are too obvious. Neither do I intend, at present, to point out all the similarities and dissimilarities between the various organisms which range themselves along the two great lines of life that the ox and the oak represent. The task would be too Titanic. But we may profitably consider the point raised by the bright-faced boy, acquiesced in by his father, and shared by many another father and mother. Animals can move, and plants cannot! We may at once make up our minds that the statement is not true: the title of the present article tacitly assumes that. Plants do move; but how, and why, and when?

Perhaps, if we had fixed our boy's father a little more closely, he would have grudgingly assented that the stem of a plant goes up, and the roots go down, that flowers open to the light, and sometimes close in the dark; and, if he had diligently read the first volume of CASSELL'S POPULAR SCIENCE, that leaves have their waking and their sleeping moments,* and that others are so many snapping jaws to catch the unwary fly.† Yet he would profess to see a great difference between these movements and the leisurely steps of the patient Jersey milker amongst the sweet grass.

There is no gainsaying the statement that many of the common movements of plants are due to what may be called growth. But what is growth? Change of form *plus* increase in bulk. We are not, then, much farther advanced. The procuring of food is only a phase, as it were, in growth, or rather a movement or series of movements prompted by the necessities of growth. Here we begin to see a hazy sort of resemblance between our Jersey stepping daintily among the grass and the plant whose roots strike deep down to the most favourable points of food supply. "Oh, but the cow moves of its own volition," is perhaps the doubting reply. It is a "free-willer," to quote a now hackneyed phrase. I must confess that I do not see where the free will comes in. The cow is made to move by the promptings of hunger. The plant is made to move its roots by the promptings of hunger. Ah! we see the connection now.

But the differences? Yes; there are many. The animal has a wider range of movement. It can traverse its miles in search of food—sometimes. The plant has only a limited range of movement—sometimes. We have only to think a

* "How Plants Feed," Vol. I., p. 280.

† "Carnivorous Plants," Vol. I., p. 357.

moment to remember that there are exceptions to both statements. The oyster swims for awhile, and then anchors itself to a stone or tile, and refuses to budge; the curious ascidian does likewise. Both desire of movement and power to move have gone. The fresh-water alga (*Hæmatococcus pluvialis*) (Fig. 2), which makes its home in the (to it) infinite recesses of the water-butt, has its free-swimming period too, and likewise a time when the desire and power to locomote depart; but the little *Hæmatococcus* is a plant. Harking back to the paper upon "Snow," we remember that there mention was made of another alga that possesses these same powers of movement; it is the brother and sister of our little friend of the water-butt.

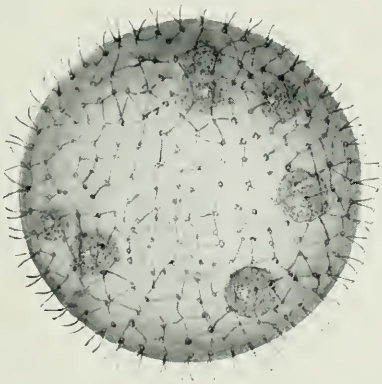


FIG. 1.—*VOLVOX GLOBATOR*, A FREE-SWIMMING FRESH-WATER ALGA.

The projecting lashes or "cilia" are in constant motion, and the sphere "rolls" along quite briskly.

Not the least interesting of the algæ which possess undoubted powers of movement is *Volvox globator* (Fig. 1). Although small, it is not so tiny but what it can be seen with the naked eye. Take a little water from a pond or ditch, put it into a glass vessel, and hold it up against the light. Probably a number of bright green specks will be seen swimming about; they are the *volvoxes*. Under a low power of the microscope they reveal themselves to be nearly transparent spheres moving through the water with a distinctly rolling motion. Under a higher power we get the appearance which the artist has portrayed for us in Fig. 1. We see then the reason why the *volvox* moves. The sphere is composed of a great number of cells, and from each cell protrudes two slender lashes, or *cilia*, as they are technically called. It is the continual lashing of these *cilia* which causes the sphere to move. If we compare a *volvox* to a round boat propelled by innumerable oars we shall not be far wrong.

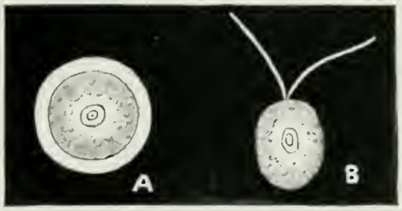


FIG. 2.—A FREE-SWIMMING ALGA (*HÆMATOCOCCUS PLUVIALIS*), WHO MAKES HIS HOME IN THE WATER-BUTT.

A, free-swimming stage; B, quiescent stage, when the organism has lost both the desire and the power to move.

Take again the curious spores of those fungoid pests which bring to us potato disease and wheat rust, and a thousand other ailments. All these little organisms possess powers of movement, yet all belong to the vegetable kingdom. So far little has been said of the closely allied bacteria

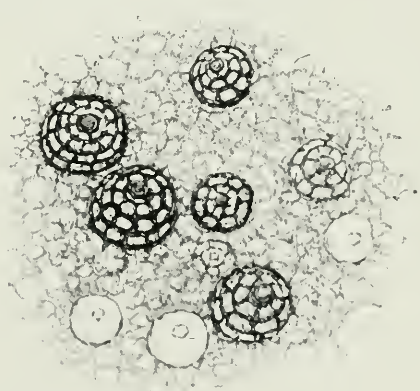


FIG. 3.—ONE OF THE "SLIME FUNGI" (*BADHAMIA UTRICULARIS*)

of which we have heard so much of recent years. It is difficult to place them definitely, for they have a code of etiquette entirely their own. Many biologists have got out of the difficulty by placing them upon neutral ground between the plant, on the one hand, and the animal, on the other, because they have affinities with both.

Take another group of beings, the *Myxomycetes* which lie in this Tom Tiddler's ground of biologists. They consist, as far as their vegetative part is concerned, of a mass of slimy, creeping protoplasm, termed technically a *plasmodium* (Fig. 3). From this central mass feelers are continually being pushed out and pulled in again, not at random, but with a definite purpose—*food*. In the case of those species which grow upon wood, these feelers will find their way to the damper portions, if there be any, which afford the most favourable source of food. Sometimes the *slime fungus*, as it is popularly called, desires to form spores, and then the "feelers" will find the driest parts of the wood, and guide the plasmodium thither. In the formation of these *spores* the "slime fungus" behaves as a true plant, but when it comes to feeding, it follows the promptings of its other affinities and behaves like an animal. The "plasmodium" literally flows round the food, engulfs it, and proceeds to digest it at leisure. Clearly, when we consider such curious expressions of life, we must revise our ideas as to the non-movement of plants, for our *Myxomycete* is just as much a plant as an animal.

The plasmodium shown in Fig. 3 belongs to *Badhamia utricularis*.

I might go on to enumerate other instances of the queer side of living things, but enough has been said to prove that—

FIG. 4.—THE STEM OF THE BINDWEED (*CONVOLVULUS*) "CIRCUMNUTATES" OR "BOWS AROUND."

The stem turns from right to left, and no amount of persuasion will induce it to do as the hop and twist from left to right.

(1) No hard and fast line can be drawn about movement being confined to animals.

(2) As we get lower and lower in the scale of life, the degree of divergence between the two lines of descent lessens; in other words, the lines converge.

It is a favourite line of argument that the so-called "movements of plants" (the inverted commas are not mine) are simply mechanical; that the root goes straight down and the stem goes straight up because of the force of gravity acting, and that it is as illogical to speak of this sort of thing as being spontaneous movement as it would be to say that the stone falls back to earth because it chooses to do so, when it is only obeying a stringent mechanical law. This would be quite true if we always found that the root went straight down and the stem went up. As a matter of fact, both stem and root give only a very half-hearted allegiance to this law of gravity. The root troubles far more about seeking its food, and the stem and its leaves are considerably more concerned about getting to the light and keeping there. When neither of these things is in jeopardy, the law of gravity

is obeyed. We know that a pot-plant in a window will grow strangely lop-sided if it is not turned round occasionally, and that if it is placed in a room to which only a chink of light is admitted, its ascending axis will invariably turn towards that chink of light. If it is kept in these conditions for many days, it will make desperate attempts to reach the light. Its *internodes* (the parts between the nodes or joints) will lengthen, whilst the green parts, or rather the parts of the leaves that are normally green, will become sickly white or yellow, and the leaves that are produced under such conditions will be very weak and puny.

Again, take the stem of a climbing plant, which we will consider in more detail shortly ; it will grow upwards, it is true, but it will take its own way of doing it. It will perhaps tend to turn round some support. Perhaps, as in the case of the convolvulus (Fig. 4), it wishes to circle from right to left ; if so, it will be of no use to try to make it turn from left to right, as the hop does. Why ? Nobody knows.

The fact is this, that at some time or other in the history of the race—not of this special member of it, be it observed—a warning was conveyed to the convolvulus that in order to reach the all-important light—which means, in order that it might continue to exist—it must contrive to raise itself above the shade of the taller plants which were slowly choking it out of existence. When an ordinary human being cannot support himself, he goes upon the parish, which means his more fortunate neighbours collectively. When a convolvulus cannot support itself, it gets its stouter neighbours to bear the burden. We notice that in this case the " support " is only mechanical ; we may liken it to " outdoor relief." There are other plants which want more, so they go inside the " House," if we may carry our simile further, and become the parasites of the plant world—witness the dodder and the broom rape.

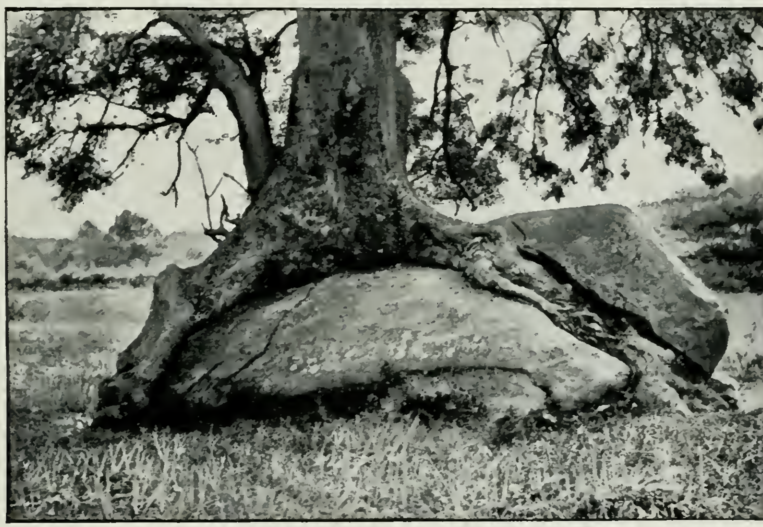


Photo: Miss Flatter, Newport, I.W.

FIG. 5. A TREE THAT SPLIT A ROCK.

It is now time that we returned from this apparent digression, which was really necessary to show that—

(1) A warning is given.

(2) A warning is received and acted upon.

If we put this into the favourite

words of the botanist, it would be: The plant is capable of receiving and responding to a *stimulus;* according to the nature of this *stimulus*, so is its behaviour. This sensitivity to stimulation is one of the fundamental qualities of *protoplasm*, and therefore of life generally. Each living cell—and there are many millions of cells in a plant—may be likened to a bagful of protoplasm which is sensitive to these "stimuli." But what are the conditions that impart a stimulus? They may be summed up as *food, light, air, temperature,* and *moisture*. Extremes under any of these heads will produce a strong stimulus. The "means" produce stimuli also, but not to such an extent, for they tell the plant that it may go on as it has been going.

FIG. 6.—AN AMBITIOUS PINE, WHICH HAS ENSCONCED ITSELF UPON A FRAGMENT OF STONE BELONGING TO AN OLD CHAPEL.

Thus our convolvulus acted upon a stimulus—that of light, or rather lack of it—and the feelers of the "slime fungus" guided the main body to the wet or dry side of the wood as was required.

It will perhaps be advisable to take the principal organs of the plant one by one, and notice in each case the principal movements which are to be observed.

Something has been said in a previous paper * about the "earth-turning" or *geotropism* of roots, and the "sun-turning" or *heliotropism* of stems. We then agreed that the root was *negatively heliotropic and positively geotropic*, and the stem *positively heliotropic* and *negatively geotropic*. The terms are formidable, but they are frequently met with in print, so we shall do well to know something of them. Put into everyday language, they simply mean that the root tends to turn towards, and the stem away from, the (centre of the) earth, and the stem to turn towards, and the root away from, the sun.

These qualities of stem and root occasionally lead to curious complications. Fig. 5 shows a tree that has been daring enough to split a rock, simply because its stem persisted in going upwards and its root downwards. The daring pine (Fig. 6) will almost certainly split the stone upon which it is growing before it has done. In both these cases the fission is directly due to the mechanical result of growth, and can no more in itself be called a movement than the water in a tumbler, which splits the latter upon being turned into ice, can be said to move. But we must remember that the indirect causes of it all are the "sun-turning" and "earth-turning" movements. The mushroom which has turned the legal occupant out of the flower-pot (Fig. 7), is an instance of mere mechanical movement, aided by a desire on the part of the fungus to reach the air (not necessarily the light)

* "How Plants Feed," CASSELL'S POPULAR SCIENCE, Vol. I., p. 280.

to secure the dispersal of its spores, and thus a succession of mushrooms.

In addition to the foregoing, roots possess a remarkable movement, which has been dignified by the name of *hydrotrophy*—water-turning. It has been said that roots can *smell* water, but without committing ourselves to this statement, and not knowing exactly what quality in the plant corresponds to *smell* in the animal, we must admit that roots find water with far greater ease and certainty than the hazel-twig and the human wielder.

FIG. 7.—A MUSHROOM EVICTION.

The mushroom has a natural desire to distribute its spores. Hence it seeks the air and incidentally turns out the rightful owner of the flower-pot.

Every amateur gardener may verify this for himself. Many a drain-pipe has been choked by greedy roots seeking the water within, and more than one closed-in well, reopened after a lapse of years to see why the pump has gone wrong, reveals a perfect network of encroaching roots. Seeking the line of least resistance is a very common-sense quality that roots have. A big stone lies in the direct path, the root cannot pierce it, neither can it find a chink or crevice into which to enter; then it simply goes round, and resumes its interrupted path when the obstruction has been got over by this judicious flank movement.

There are not wanting what may be called freak movements, both of root and stem, which fall into neither of the foregoing classes—witness the knotted root of *Fœniculum piperitum* shown in Fig. 14. It is difficult to assign a reason for this strange behaviour, and almost impossible to see what this vegetable contortionist expects to gain by its laborious twistings. It is a freak pure and simple.

One of the most important qualities of the stem is its power of what is termed *circumnutation*, or "bowing around." This means that the point of a growing shoot, especially of a twiner such as the hop (Fig. 8) or convolvulus, describes a number of curves. This movement begins as soon as the tiny stem has ruptured the seed coat, and before it has made its appearance above the soil. By it the line of least resistance through the soil to the light of day is found; then, if the plant be a stem climber, it circumnutates until it finds the support it needs. Even when it finds this support the "bowing around" still continues, so that the support is enclosed by the growing shoot with a number of "spirals," and detachment by accident is practically impossible. The stems or *petioles* of some leaves, such as those of the clematis, "bow around," and they, too, enclose the support with a number of spirals. Calculations have been made as to the force exercised by the tip of a growing stem forcing its way through the

soil. In the case of the bean, 8 lb. 8 oz. was given as the result of the calculation, and this is not by any means the maximum. The strictly mechanical expansion due to growth is undoubtedly responsible for much of this force, but circumnutation must also be considered as a not unimportant factor.

This movement of nutation in itself presents a great variety of interesting facts. If we liken the plant to a clock of which the circling shoots are the hands, it will give us some idea of what goes on. The hands of the clock move fast or slow according to the weather; thus in warm weather the tip of a healthy hop shoot

FIG. 8.—THE HOP IS ALSO VERY POLITE AND "BOWS AROUND."

Its twist is from left to right. Compare with the Convolvulus in Fig. 4.

will take a little over two hours to complete the circle, while the bindweed does not want more than an hour and a quarter. Some other climbers take even less time; and, again, there are others which require forty-eight hours to perform the journey. As previously stated, the weather has a great deal to do with it, for

FIG. 9.—ONE OF THE BIRTHWORTS (*ARISTOLOCHIA CLEMATIS*).

These peculiar flowers treat their insect visitors very shabbily. As soon as the flower has benefitted by the pollen brought, the "flap" at the top closes over and keeps the guest in durance vile. Sometimes he starves, but usually he escapes with nothing more than a fright and a warning.

movement is always inclined to be sluggish when the temperature is low. Now, however difficult it may be to explain *how* it is that the stimulus received by the protoplasm makes the shoots of the hop and the bindweed act in this way, it is quite easy to see *why* it is done. These plants have inherited the climbing tendency, and to climb they must have something to climb upon. That something may not be situated quite close to the main stem of the hop or bindweed, so the plant has to search for it. The circling shoots, then, are feelers sent out to discover what available support there is in the neighbourhood. Having found the support, it is utilised, and the circling movement of the shoot below the point of contact with its support ceases. But the tip of the shoot con-

tinues to "nutate," and the result is that the support is speedily gripped by the encircling spirals of the climbing stem. A message is meanwhile sent to headquarters by means of the sensitive protoplasm that all is well.

In the paper upon "The Sleep of Plants," attention was drawn to the fact that many leaves took up different positions by day from what they did during the night, and when dealing with "Nerves and Nervelessness" it was pointed out that the telegraph plant and the sensitive plant possessed something closely akin to nerves. Touching a sensitive plant to see the leaves fold up has for long been a favourite pastime with inquisitive youth, and the

FIG. 10.—A LIANE STEM, SHOWING THE TWISTING CAUSED BY "BOWING AROUND."

The trees in tropical forests are commonly wreathed by these climbers, and as the twisted stems have almost the toughness of hempen ropes, progress is difficult. The machété has to be continually in use, for a path has to be cut.

movements are, to say the least of it, rather peculiar. Not less curious are the movements of those carnivorous plants which catch their prey by traplike arrangements formed by hairs and spines. In each case it will be remembered the "jaws" of the trap are closed as the result of a *stimulus* communicated by the presence of the foreign body, whether luckless fly or accidental stone.

When we come to consider flowers and seeds, a wonderful variety of movements confronts us. Nature's utilitarian ways are once more demonstrated as we observe that all these movements, complex as they may be, subserve the purpose of fertilisation or dispersal of the seed. If we take the flower of one of the quaint birthworts (*Aristolochia*) (Fig. 9), we shall find that the movable lip or flap which guards the interior opens to admit the insect with its

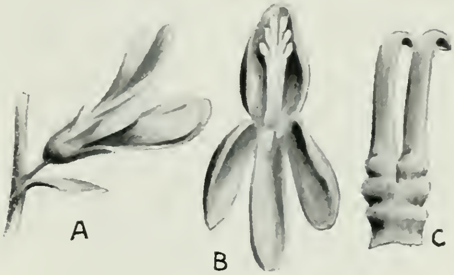


FIG. 11.—"IN *GENISTA* AN ARRANGEMENT OF SPRINGS COVERS THE INSECT VISITOR WITH POLLEN."

A, flower ready for insects; B, after explosion; C, curved stamens.

load of pollen, and closes to prevent its escape, although it does not remain closed long enough to ensure the death of the winged visitor. It only keeps him in durance until the stamens have perfected their store of pollen, which is thrust upon the insect, and sent off to fertilise the flowers. A most complicated series of movements this, and an interesting.

In *Genista* (Fig. 11) and *Medicago* (Fig. 12) an arrangement of springs results in the insect visitor being covered with pollen, some of which is deposited upon the stigma of the flower next visited. In the

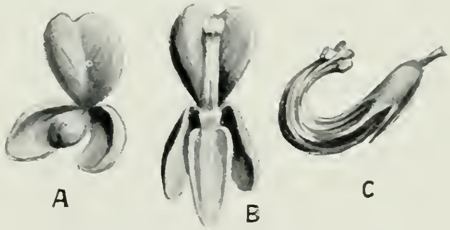


FIG 12.—THERE ARE SPRINGS IN THE FLOWERS OF *MEDICAGO.*

(References as in Fig 11.

barbery, the stamens, if touched very lightly, will bend forward towards the stigma—*i.e.* the "point" upon the *pistil* or female organ, where the pollen must be

applied to effect fertilisation. Most flowers display the "sun-turning" quality to a greater or less degree. The huge yellow circle of the sunflower faces the orb of day

FIG. 13.—THE ANIMATED OAT.

The twisted awns have hygrometric qualities, and in damp weather describe circles in an uneasy, jerky fashion, thereby screwing the oat into the soil.

from early morn till he sinks in the west; in fact, the flower appears to follow the sun. Nor is this to be taken as an isolated instance, although it is one that must be familiar to a great many. The pretty spring crocus is even more sensitive. Let the morning be bright, and the flower opens gladly to welcome the sun; but let it be dull and murky, and the flower sulks, and refuses to open. Even a passing cloud, if it be a fairly heavy one, disturbs the equanimity of the crocus bloom, for clouds mean rain, and rain would mean that the pollen would be damaged or completely spoilt. So the crocus tries to close, so sensitive is its mechanism, and so nicely adjusted are its movements to external influences.

The curious fruits of some species of oat afford a highly interesting example of a movement that is governed by hygrometric properties. The illustration (Fig. 13) shows the bearded fruit, with the long, twisted awns. As long as the fruits are lying in a dry room no movement is to be seen; but place them in damp, warm surroundings, or, better still, breathe upon them several times, and the awns begin to twist and turn the fruits over and over. It is almost uncanny to watch these jumping oats, for the motion is jerky, and sometimes rather sudden. The value of the movement is that it tends to screw the oat into the soil after natural dispersion. The stiff bristles which clothe the lower part point upward, and, while they do not hinder the passage into the soil, they prevent the passage out once the rotatory awns have done their work. This oat is therefore its own sexton, but it will only work in damp weather.

Many further instances of the movements of plants might be adduced, but enough have been given to prove that this faculty of movement, although it may not have so wide a range with regard to distance as it has in the animal, has yet to be reckoned with. Further, we bear in mind that all these movements subserve the welfare of the plant in a more or less marked degree. We have only to look

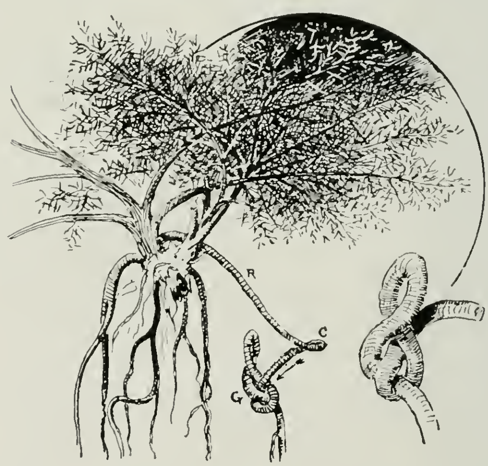


FIG. 14.—A FREAK ROOT.

The root, R, has given one turn at C, tied itself into a knot at G, and then resumed its downward progress, its equanimity apparently undisturbed by these gymnastics.

around us into that great book of Nature to find other instances for ourselves. There is always a reason to be found, but the finding is only to the whole-hearted seeker.

A PIECE OF LIMESTONE.

THOSE who have had the good fortune to spend a holiday in one of the great limestone districts of England —say in Derbyshire, in North Lancashire, in the south-west of Westmorland, or in the West Riding of Yorkshire—will be willing to endorse the statement that there are few fairer regions in our own fair country. The high and breezy uplands are studded with masses of bare grey rock, seamed by deep and regular fissures, in the cool shade of which flourish miniature forests of snaky hart's-tongue or delicate bladder-fern. All round the tops of the hills run great terraces of gleaming limestone, and their slopes are covered with short, crisp grass of the brightest green. In the hollows grow clumps of spreading trees, in delightful contrast to the white and glaring roads. Every here and there, springs of water well forth out of the ground, and from them clear streams make their way down to the sea through deep and narrow gorges, dashing themselves into foam over rocky ledges, or wearing their stony beds into a thousand fantastic shapes.

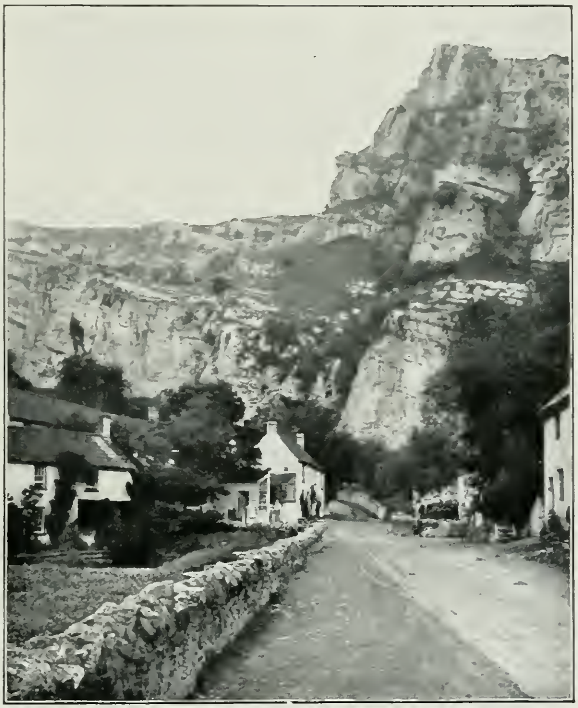


Photo: T. C. Hepworth.

FIG. I.—LOWER ENTRANCE, CHEDDAR CLIFFS.

In some of the more typical limestone districts—such as Derbyshire, Gloucestershire. or Somersetshire—we might find a thickness of from one thousand to perhaps three thousand feet of pure limestone, with hardly any intermixture of other kinds of rock. In other localities —as in Westmorland, Cumberland, Lancashire, and Yorkshire — we should find numerous beds of limestone, amounting in the aggregate to a great thickness, separated by beds of sandstone and shale. In the latter case even a superficial observer would recognise the limestones, from the fact that they stand out boldly as prominent "scars," the intervening slopes being occupied by the softer rocks with which they are associated.

Apart, however. from its scenic effects, limestone is one of the most useful and important of all the substances which enter into the composition of the crust of

the earth, and it is well worth our while to know what it is and how it was produced.

The first thing we have to do is to procure a piece of limestone—a feat very easy of accomplishment in almost any part of this country. If we have obtained a specimen of any ordinary limestone, we shall find that we have a greyish or bluish rock, sometimes nearly white, sometimes black, sometimes pink or brown, of a hard, compact texture. The broken surfaces of the piece often look somewhat crystalline—that is to say, we can see that the rock is to some extent composed of separate crystals, much as in loaf-sugar, though to a much smaller degree. At other times the texture is extremely close and fine-grained. As a general rule, the naked eye will tell us nothing more about limestone than the above, though there are cases in which we might learn more.

If we wish, however, to unravel the history of limestone, we must go much deeper than the eye alone would lead us, and we must ask the assistance of several branches of science. Let us first see what we can learn as to the chemical nature of limestone—a point of fundamental importance, both from the scientific and the commercial aspect of the question. If we take a piece of limestone and heat it strongly in a furnace, we find that it becomes much lighter in colour and much more friable—or crumbling—in texture, and we find, further, that though apparently unaltered in bulk, it has lost a considerable portion of its weight. It now possesses properties which are quite different from those of limestone itself, and it is generally known as "quicklime." The chemist will tell us that quicklime is *lime* properly so called; so that we have here *one* of the constituents of limestone. What, however, has the limestone lost which would account for its decrease of weight and change of properties in its conversion into quicklime? It has lost, as we could easily convince ourselves, two things, both of which were expelled from the furnace by the heat in a form invisible to the eye. One of these is *water*, driven off as steam or vapour by the heat. The other is the transparent gas, with which we are so familiar as the aërating agent in soda-water or lemonade, and which chemists call *carbon dioxide*, or carbonic acid gas (CO_2). Many a homeless wanderer, who has hailed the grateful warmth of the lime-kiln and made himself a sleeping place near, has fallen a victim to the poisonous fumes exhaled by the burning limestone, as the records of various coroners' courts abundantly testify.

In technical language, then, limestone is a compound of lime and carbonic acid gas—that is, a carbonate of lime, containing a certain amount of water, and mixed with a greater or less amount of various impurities, such as clay, silica, and iron. When we heat limestone, we drive off the water and the gas, and the lime is left behind, along with all non-volatile impurities. This fact is at the bottom of the process of lime-burning.

Whether pure or impure, whether artificially prepared by the chemist or under the numerous natural forms of limestone, carbonate of lime possesses one property which is of great importance as bearing upon the question of the origin of limestone—namely, it is capable of being to a greater or less extent dissolved by water impregnated with carbonic acid gas. All natural waters contain more or less of this gas, and carbonate of lime is one of the commonest of minerals. Hence almost all spring water contains more or less of carbonate of lime in solution—a fact which we express by saying that the water is "hard." The water of the sea also has a certain amount of lime dissolved in it, and so have the waters of rivers and lakes. In some cases—especially

Photo: T. C. Hepworth.

FIG. 2.—MIDDLETON DALE: A TYPICAL LIMESTONE DISTRICT.

in the instance of springs in volcanic districts, the waters of which are highly charged with carbonic acid—the amount of lime held in solution in the water is extremely large. When such lime-impregnated waters, however, are exposed to the air, their carbonic acid escapes, and the lime, deprived of its natural solvent, is thrown down in its original solid form. It is not uncommon, therefore, to find great beds of limestone which have been produced in this way at the points where springs of this kind break forth at the surface. Similar but smaller deposits of lime are commonly formed by the springs or rivers of limestone districts, as shown by the familiar phenomenon of "petrifying springs." The accompanying illustration of the petrifying well at Matlock shows the curious effect produced upon objects touched by these limestone waters. The long pendants of carbonate of lime (stalactites) which hang from the roofs of caves or decorate the joints of the mortar in old bridges, and the layers of lime (stalagmite) thrown down on the floors of many limestone caverns, are further instances of the deposition of lime directly from water holding it in solution.

Photo: T. C. Hepworth.

FIG. 3.—PETRIFYING WELL AT MATLOCK, DERBY.

The miscellaneous collection of articles seen here has been "petrified" by exposure to the lime-containing waters which issue at this point.

Though the formation of limestone by direct chemical action is thus a common one, nevertheless we cannot ascribe the production of any of the more important masses of limestone which we find in the crust of the earth to any process of this kind. Chemical action there still is; but it is chemical action controlled and modified by the potent magic of the living organism. We have seen that the waters of rivers, lakes, and seas contain a certain amount of carbonate of lime in solution, invisible to the naked eye and without form. Think, now, how

many of the creatures inhabiting these same waters possess more or less elaborate skeletons of lime. The beautiful shells of our ordinary molluscs or shell-

FIG. 4.—FORAMINIFERA UNDER THE MICROSCOPE.

These are the humble little creatures whose shells have helped to form the mighty limestone cliffs shown in Figs. 1 and 2.

fish, the exquisite envelopes of the microscopic *Foraminifera** (Figs. 4, 5, 6, and 11), the minute shells of which are found in the sands of the sea-shore or in the ocean ooze (Figs. 6 and 11), the armour of crabs and lobsters and other wrongly called "shell-fish," the prickly cases of the sea-urchins, and the skeletons of many other aquatic animals, are formed of carbonate of lime wholly or in great part. The link between these two facts is direct and unavoidable. All living beings inhabiting water and possessing a skeleton of lime derive the material of that skeleton directly from the water in which they live. Hence, though the rivers are constantly carrying down to the ocean the carbonate of lime which they hold in solution, the undue increase of this substance in the water of the sea is prevented by the equally constant appropriation of it by myriads of marine animals, which again reduce the lime to its solid form and store it away in their tissues, giving it at the same time the unmistakable stamp of *organic form.*

Let us now apply the above facts to the solution of the problem as to the origin of limestone; and to do this thoroughly we must look at limestones from different localities, or from different beds in the same locality. We cannot do better than look in the first place at a piece of one of the "marbles" of Derbyshire, merely premising that a "marble" is nothing more—necessarily, at any rate—than a limestone which is hard enough to receive a brilliant polish. Such a limestone, especially when seen in

FIG. 5.—FORAMINIFERA ISOLATED.

(From a photo-micrograph by W. Moss.)

polished slabs (Fig. 10), is found to be composed of little else than the calcareous stems of the animals which naturalists know as the sea-lilies or crinoids (Fig. 7). A few of these beautiful animals, resembling small star-fishes rooted to the sea-

* The Foraminifera are extremely simple animals, the living matter of which is hardly differentiated at all. Some of them are, however, capable of producing for themselves a beautiful, and often mathematically regular, shell of lime, while others content themselves with sticking sand grains or sponge spicules together to form a covering. Long processes of delicate living material are protruded from the shell and find an exit by the mouth alone, or in one division by pores in the wall of the shell. Most of them are so small as not to be visible except under the microscope; for this reason they have unfortunately never received any popular name. Small as they are, the sand of the sea-shore is often largely made up of their shells.

bottom by a long, jointed stalk, are found living in the depths of our present seas, but their numbers are very few. Here however, in Derbyshire—and, indeed, in

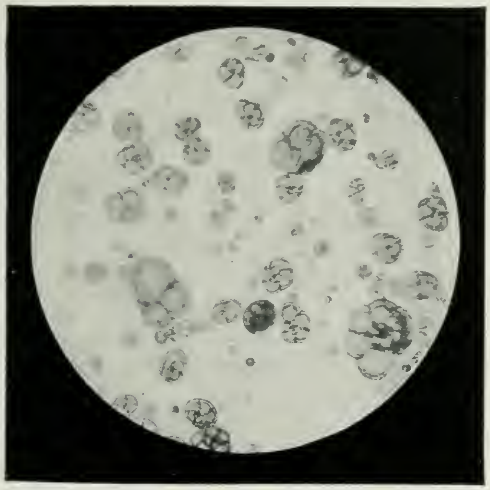


FIG. 6.—THE COMPOSITION OF GLOBIGERINA OOZE AS REVEALED BY THE MICROSCOPE.

The grey-white ooze with which the Atlantic floor is to a large extent covered is found to consist almost entirely of carbonate of lime, and this is chiefly supplied by the shells of long-dead foraminifera. The ooze from which this specimen was taken was brought up by the "Challenger."

many other parts of Britain—we have whole beds of limestone, of great thickness and covering vast areas, composed of nothing more than an aggregation of the broken stems of these elegant creatures, all bound together by a calcareous cement. Now, all known sea-lilies are denizens of the sea, and it is therefore a matter of certain deduction that the beds of Derbyshire marble, and all other limestones of a similar character* in other places, existed at one time in the form of great banks and forests of these animals in a *living* condition. They were either formed by the growth of successive generations of crinoids *in place*, or they were formed by the heaping up by the waves and currents of the sea of vast accumulations of their skeletons in a more or less broken and fragmentary condition.

Here is another piece of limestone (Fig. 16), again, which is composed of the skeletons of coral polypes, in all essential respects similar to the coral-producing zoöphytes of recent seas: entire beds of the limestone are made up of these beautiful structures, often standing erect, as they originally grew on the sea-bottom. In this case not only do we know that the limestone was formed beneath the waters of the sea (all known corals being marine), but we are fortunately enabled to point to precisely similar limestones now in process of formation. If we transport ourselves to the West Indies, the Pacific, or the Indian Ocean, we find that vast deposits of limestone are now being laid down in the sea, in the form of coral reefs. These cover enormous areas, and may be continuous for hundreds of miles, and they are composed principally of the calcareous skeletons of the beautiful coral polypes (Figs. 18 and 19)—animals resembling the sea-anemones in fundamental structure, but capable of secreting for themselves a calcareous support or framework, over which their soft and brilliantly coloured bodies are spread. Whilst parts of the reef are composed of the skeletons of the corals standing erect as they grew, other parts are made up of broken-down corals, which have been reduced to fragments by the waves of the sea, mixed up with shells of all kinds, and often with the

FIG. 7.—A LIVING SEA-LILY OR CRINOID, SHOWING HEAD AND UPPER PART OF JOINTED STEM.

* As the sea-lilies are technically called "crinoids" or "encrinites," it is usual to speak of all limestones which are composed of their skeletons as "crinoidal limestones" or "encrinital limestones."

limy skeletons of sea-weeds. These accumulations of calcareous *débris* soon harden into solid rock, and then reproduce for us, in almost every particular, the ancient coralline limestones with which the geologist is so familiar. In the case of these latter limestones, then, as in that of the crinoidal limestones, we have certain proof that the rock was formed beneath the sea, and that it is essentially composed of the skeletons of living beings.

Here, again, is another piece of limestone which is full of different kinds of shells, for the most part quite perfect. In this case the *organic* origin of the rock is as clear as in the preceding instances, but the rock would not necessarily have been formed in the sea. Some limestones contain shells which resemble our living oysters, mussels, whelks, cockles, and periwinkles, and such are all of marine origin, since these shells all inhabit salt water. Other limestones, again, are full of the remains of shells which so closely resemble our living river-mussels and pond-snails as to leave no doubt that their habits of life were the same. These limestones, therefore, were formed in fresh water, and are composed of the skeletons of animals which lived in rivers or lakes.

The three pieces of limestone which we have hitherto been examining all contain the whole or broken skeletons of animals large enough to be conspicuously visible to the naked eye. Not only is their size considerable, but the skeletons in question are so obviously identical with the skeletons of now living animals that the only wonder is that they should have been so long passed over—as they still are by many who have not learned to use their eyes—or that their animal nature should ever have been doubted ; this last feat, however, having only been accomplished by people who did not *want* to believe that they could be the remains of beings that were once alive. So far, then, it is tolerably plain sailing ; but there are very many specimens of limestone in which we shall find few or none of these conspicuous animal remains, such as sea-lilies, corals, or shell-fish, and the whole of the greater part of the rock would appear to the unassisted vision to be simply compact and structureless. At this point of our inquiry we have to call

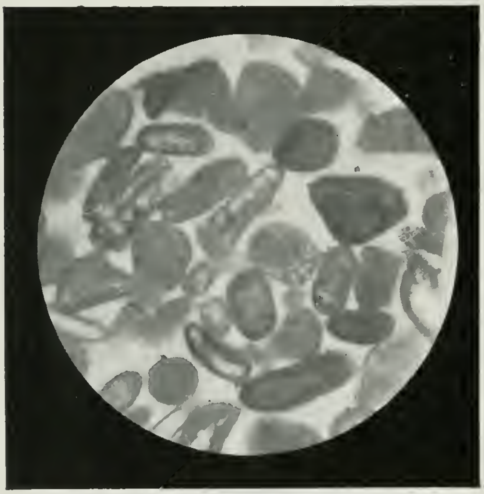


FIG. 8.—LIMESTONE UNDER THE MICROSCOPE.
Compare with the close formation of granite.

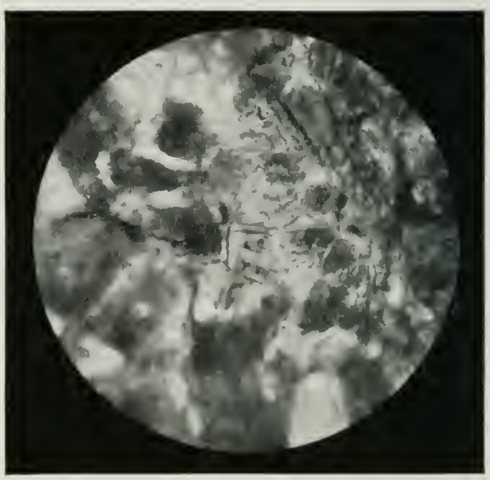


FIG. 9.—GRANITE UNDER THE MICROSCOPE.

to our aid an instrument the value of which in geology is now fully recognised—namely, the microscope. We cannot,

FIG 10.—A PIECE OF CRINOIDAL LIMESTONE, GROUND THIN, POLISHED, AND PLACED UNDER THE MICROSCOPE.

The stems of the contained "Crinoids" can now be seen.

of course, obtain much benefit by simply placing a piece of limestone under the microscope, though sometimes something may be done even in this way. It is not, however, a matter of great difficulty, by processes which need not be further alluded to here, to obtain a slice of limestone (or of any other rock) so thin that it can be seen through with the greatest ease. By this means we can render the magnifying power of the microscope readily available in the elucidation of the intimate structure of the most dense and compact of rocks.

If, then, we take such a transparent slice of any ordinary compact limestone, which shows few or no indications of its containing animal remains, so far as the naked eye is concerned, what do we see on submitting this to the microscope? As a general rule, we should find that the apparently structureless mass is instinct with the traces of bygone life. Instead of a mere crystalline or granular aggregate, our eye would delightedly recognise innumerable fragments of the skeletons of all kinds of marine animals, such as sea-lilies, or corals, along with, in many instances, entire and beautifully shaped microscopic shells, the whole bound together into a solid mass by a calcareous cement (Figs. 8, 10, and 16). We should therefore have no difficulty in recognising that the rock is really of *organic* origin, and that it is composed of the minute skeletons of microscopic animals, or plants, or of the fragments of the skeletons of larger forms.

We ought, however, to go further than this, and our demonstration would not be regarded as complete unless we could point to some similar limestone now in process of formation in our own seas. The "coral rock" of many coral islands is largely composed of microscopic calcareous organisms, or of the broken-down *débris* of the skeletons of larger beings, and therefore in part supplies us with the parallel we want; but we may find a better example still. Everybody knows the soft, earthy, white limestone which we generally call chalk. Let us see what modern science has taught us as to the

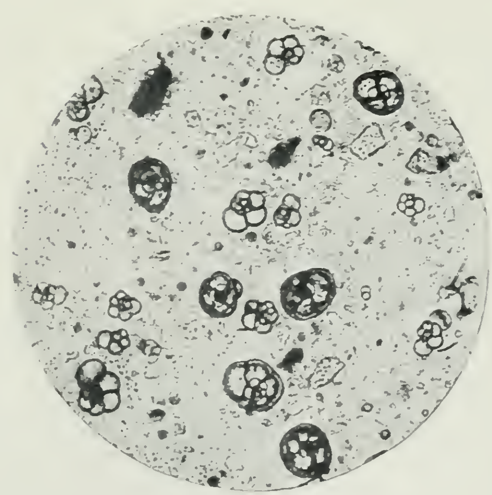


FIG. 11.—MORE GLOBIGERINA OOZE.

Brought up by the "Challenger" from a depth of 1,990 fathoms.

real nature and constitution of this substance, long one of the puzzles of the geologist. The white chalk covers an immense area in Europe, and attains a

thickness at times of a thousand feet; and as it is throughout composed of more

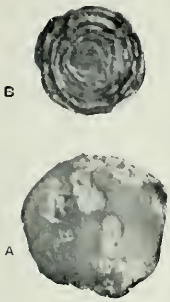
FIG. 12.—A PERFORATE TYPE OF FORAMINIFERA.
Showing the processes which issue from the pores in the shell when the creature is alive.
(After M. Schultze.)

or less soft and powdery carbonate of lime, it is no matter for astonishment that the older geologists felt a difficulty in bringing forward any satisfactory theory as to its origin. From this difficulty they were relieved by the microscope on the one hand, and on the other hand by those marvellous investigations which have of late years been carried out as to the nature of the sea-bottom at great depths. If you make a thin slice of chalk sufficiently transparent to be seen through, and examine it by means of the microscope (Fig. 13), you will find that. instead of being composed merely of grains of carbonate of lime, as we might expect, it is really made up of fragments of the skeletons of various marine animals, mixed with innumerable chambered calcareous shells of microscopic size, the whole united together by a granular calcareous base. The little chambered shells just spoken of belong to the minute animals which the zoologist calls *Foraminifera,* and though of common occurrence in many of the ordinary limestones, it is not often that they are found —as in chalk—in such numbers as almost to compose the entire rock. Chalk, in fact, may be properly described as a soft *foraminiferal* limestone, since these minute and beautiful shells are the principal element in its composition.

We have, therefore, to begin with, to endeavour to adequately comprehend the wonderful fact that we have in the chalk a rock occupying hundreds of square miles, and attaining hundreds of feet in thickness,

FIG. 13.—CHALK UNDER THE MICROSCOPE.
For comparison with limestone.

which is essentially composed of the calcareous envelopes of animals so small as to be practically invisible to the naked



FIGS. 14 AND 15.—A NUMMULITE.

A, external view; B, a section, showing chambers. This little creature also belongs to the Foraminifera. Nummulitic limestone was quarried by the ancient Egyptians, and employed to build part of the Pyramids.

eye. Some *Foraminifera* are, however, large enough to be easily seen or handled, as, for instance, the nummulites, which are as large as small coins, and make up a considerable part of some limestones (Figs. 14 and 15). For our knowledge of the modern representative of the chalk we are indebted mostly to the deep-sea soundings carried out in H.M.S. *Cyclops* for the purpose of finding a suitable track for the Atlantic cable, and later to the deep-sea dredgings prosecuted in the *Lightning*, *Porcupine*, and *Challenger* expeditions, which were sent out for the purpose of clearing up our ignorance as to a great many points connected with the condition of the ocean and its bed at great depths. From these, as well as other sources of information, we know that there is now forming in the abysses of our great oceans a deposit which is essentially similar to unconsolidated chalk. This deposit, often called the "Atlantic ooze," is found at great depths in both the Atlantic and Pacific Oceans, covering areas of vast extent, and presenting itself as a whitish-grey, impalpable mud, very like greyish chalk when dried. Chemical examination shows us that this ooze is composed almost wholly of carbonate of lime, and the microscope reveals the fact that it is principally made up of the microscopic chambered shells of *Foraminifera*, many of these being absolutely indistinguishable from the *Foraminifera* of the chalk. If, therefore, the Atlantic ooze were once consolidated and converted into rock, it would present us with an almost complete parallel to the true white chalk of geologists.

FIG. 17.—WEATHERED LIMESTONE.

Here the Crinoids stand out in relief. The surroundings, being softer, have succumbed more quickly to the influence of wind and weather.

Chalk, then, is only another example in support of the general statement that the majority of limestones are of organic origin, and are composed of the calcareous skeletons of animals and plants. Of the truth of this general statement we can have no doubt whatever, for it admits of direct demonstration: but there are some cases in which we must of necessity rely upon analogy simply. The only case of this nature which needs to be alluded to here is that of the hard and crystalline limestones which constitute most, though by no means all, of our ornamental

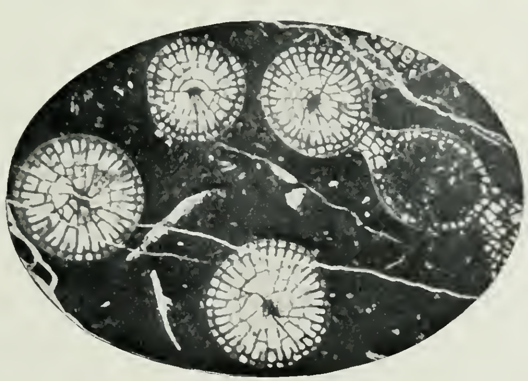


FIG. 16.—A PIECE OF CORAL LIMESTONE CUT AND POLISHED, AND PLACED UNDER THE MICROSCOPE.

Observe the corals in section.

marbles. If we look, for example, at the beautiful white statuary marbles of Carrara, we should fail to find any direct proof that they were of organic origin. The microscope would show them to be composed of nothing but smaller or larger crystals of carbonate of lime confusedly mixed together, just as a lump of loaf-sugar is made up of crystals of sugar. We have, however, every reason to feel sure that these crystalline marbles were at one time nothing more than ordinary limestones, and, like these, were originally composed of the skeletons of various animals. They lost their primitive condition, and assumed their present crystalline state, in consequence of their having been subjected to the action of heat combined with pressure, as the effect of which the particles of the rock underwent a complete rearrangement, assuming a crystalline form, and thus necessarily obliterating all traces of their original organic nature. That this is no mere theory is proved by the fact that in some crystalline marbles the change above spoken of has not affected all parts of the mass equally, so that in places we may find the rock less affected than elsewhere, and here we may meet with organic remains. Another proof of the correctness of this view is afforded by the phenomena observed when any ordinary limestone comes in contact with a mass of rock (such as a bed of lava) which we can show to have been at one time in a melted condition. In such cases the limestone in the immediate vicinity of its once heated neighbour is found to be converted into highly crystalline marble, and to have lost all traces of its original organic structure; a little farther off from the lava it is hardened and perhaps slightly crystalline; and still farther off again it has retained its ordinary condition, and is crowded with the remains of animals.

FIG. 18.—A PIECE OF RECENTLY FORMED CORAL.

Speaking broadly, then, we may regard it as established that the great masses of limestone which we find so largely developed in the crust of the earth are really of organic origin, and that a very considerable portion of the solid framework of our globe is thus composed of the calcareous skeletons of innumerable generations of animals and plants, many of which were individually of microscopic dimensions. Nor has this process of lime-making been confined to any one period of the earth's history or to any one place on its surface. On the contrary, it has gone on ever since the first introduction of life upon our planet, and it has occurred in all areas covered by the ocean. Hence we have limestones belonging to almost all the great geological periods, and forming a constituent of the land in all our great continents. We have, lastly, in the fact that limestones are composed of animal remains, a conclusive proof of the oscillations of level, the subsidences and the elevations, to which the apparently immovable dry land has been subjected at successive periods. The construction of the ordinary limestones out of the skeletons of marine animals is an incontrovertible proof that

these rocks could only have been deposited beneath the waters of the sea. Every region, therefore, where we now meet with one of these marine limestones, must at one time have formed a portion of the sea-bottom. Every limestone thus marks, in the place where it occurs, a depression of the crust of the earth beneath the sea-level. On the other hand, every marine limestone which we now find forming part of the dry land marks, at the point of its occurrence, an elevation of the crust of the earth above the sea-level by means of those great subterranean forces which are always at work over some portion or another of the earth's surface. Thus, an ordinary piece of limestone, such as we may pick up on any roadside, rightly considered, brings us at once into living contact with the slow but ceaseless action and interaction of those great natural forces by means of which the exterior of our planet has assumed its present structure and configuration.

FIG. 19.—CORAL AND CORAL-BUILDERS

The Polyps of a piece of red coral.

(After Lacaze Duthiers.)

A POND AND ITS INHABITANTS.

"AS dull as ditch-water" is a good old English saying, carrying us back to a time when the accurate and scientific study of natural history was a thing undreamt of by our forefathers. In those good old days it was believed that bats were blind and toads spat fire; and he who dared to doubt it, or manifest any interest in the works of nature, was quickly suspected of being in league with the Evil One, and treated accordingly. With the advance of knowledge many of these old popular notions died out, and the invention of the microscope, and the subsequent improvements in it, gradually brought to light the fact that the duller and dirtier the ditch, the more it teems with innumerable minute living beings. The popular mind, nevertheless, still clings with limpet-like tenacity to the old saw, and fails even yet to realise the importance of the discovery, either through sheer ignorance, or the want of a due appreciation of the works of nature. Next to the ditch, the pond might seem, from one point of view, about the dullest thing imaginable; and yet both the microscopist and the naturalist know that it is one of the finest "hunting-grounds" possible. The geologist, too, will, when consulted, testify that more may be learnt from half an hour's careful observation of what is taking place at the edge of a pond where a stream is running into it than by many days' reading.

This, to be understood, must be put to the proof. The would-be naturalist must seek out the nearest pond, and there on its banks work out its history for himself.

The first point he will have to consider will be the apparently trivial question of "What is a pond, and how are ponds formed?" We say "apparently trivial," because it is in the careful reasoning out of seemingly simple questions such as these that some of the grandest laws of nature become clear to us.

Our naturalist probably settles in his mind that a pond is nothing more nor less than a hollow in the ground filled with water, and, having disposed of that head, will find, as Hercules did in the Hydra, two others in place of it, viz. "Whence did the water come?" and "How was this hollow or depression formed?"

In response to the former question he will first call to mind how, when the rain is falling on soil into which it cannot soak, the water, seeking the lowest level, runs into the minor inequalities of the ground and forms puddles. Then, arguing from the less to the greater that the bigger the hollow the bigger the puddle, he at length arrives at one sufficiently large to be dignified by the name of a pond. Ponds, again, range upwards in size, until they lose the name and become lakes.

To the second question our friend might urge that these hollows were merely due to the wearing and tearing action on the earth's surface of the various atmospheric agencies, and that, though the slope of the surrounding ground might be imperceptible to the eye, yet the water, unerringly obeying the law of gravity, has collected in this the lowest spot of all. To this we may add that a local subsidence, following on the removal by water of earth below the surface, may likewise give rise to a pond, as will also the formation of a barrier, whether natural or artificial, thrown across the valley of a stream. Since water-tightness is a necessity for their existence, and as, in nine cases out of ten, clay is the material that insures this qualification, it follows that ponds are

THE LIFE CYCLE (METAMORPHOSES) OF INSECTS.

1, DRAGON-FLY (*LIBELLULA DEPRESSA*); 2, LARVA; 3, INSECT EMERGING FROM NYMPH OF DRAGON-FLY; 4 PERFECT INSECT; 5, CATERPILLARS; 6 CHRYSALIS OF A BUTTERFLY (*VANESSA IO*); 7, PERFECT INSECT; 8, LARVA; 9, NYMPH OF A WATER BEETLE (*DYTISCUS MARGINALIS*).

most abundant on clayey soils, and not infrequently do they indicate to the field-geologist the presence of this rock in places

FIG. I.—THE SURFACE OF THE POND IS GREEN WITH INNUMERABLE FLOATING PLANTS—THE DUCKWEED *(LEMNA MINOR)*.

where it might not otherwise have been suspected.

When we have satisfactorily solved the question as to the causes that brought our pond into existence, we shall be at liberty to consider what is in it.

This, we shall find, is a less easy task, and can only be accomplished by paying a series of visits at different times of the year.

The first thing that strikes the eye on approaching a pond is the thick green carpeting spread in patches over its surface. This carpet and the innumerable little floating plants that compose it are well known to all as the common duckweed (*Lemna minor*). Some of these plants—duckweeds—with their long roots are illustrated in Fig. I.

There are two other species of duckweed to be found in England.

Peeping out amongst the duckweed, the lancehead-shaped leaves of the Broad Pond-weed (*Potamogeton natans*) are to be seen ; or, perchance, instead, the round ones of the Frogbit (*Hydrocharis Morsus-Ranæ*).

Below the surface the Water-milfoil and *Elodea* form a vast sub-aqueous forest, thickly tenanted by water creatures.

This latter plant was only introduced into Britain from North America in 1847, but it speedily became so abundant in some places as to impede the navigation of rivers and canals.

With the plants of the pond, however, we have less to do at the present moment than the animals, and accordingly turn our attention in that direction, passing in brief review the more important examples.

In yonder sunny corner the surface of the water is kept in constant agitation by numerous small, shining, black specks moving in and out and round about each other with untiring activity. If this state of perpetual motion may be taken as a sign of its happiness, the Whirligig Beetle

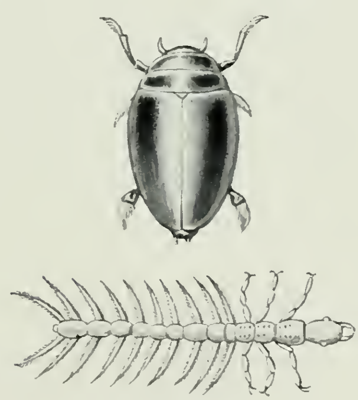


FIG. 2.—THE WHIRLIGIG BEETLE *(GYRINUS NATATOR)* AND LARVA.

This creature is one of the most successful exponents of "perpetual motion": it lives in a whirl of excitement.

(*Gyrinus natator*) (Fig. 2), for he it is, ought to be the merriest of the pond dwellers.

There is a peculiarity in the structure of the eye of this beetle worthy of our notice. Each of these organs is divided by a longi-

tudinal partition into two parts, which practically endows it with four eyes. Of these, one pair is directed upwards and keeps a sharp look-out for the approach of danger from that quarter; whilst the other, directed downwards, superintends the commissariat department.

The prey, which consists chiefly of small insects, is seized by the fore pair of legs, which are lengthened for that purpose, the two hinder pairs being modified into short and broad paddles, whereby the insect is enabled to perform its marvellous gyrations.

The lord over all the water insects, however, is the big fellow now rising to the surface for the purpose of taking in a fresh cargo of air, which he carries between his wing-cases and body. They are all air breathers, these water insects, and as readily drowned as you or I. Having laid in an adequate supply, off he starts again in pursuit of fresh victims. Indeed, the water creatures have no more formidable enemy than this same Plunger Beetle (*Dytiscus marginalis*) (Fig. 3 and Coloured Plate), defended as he is from all attacks by a suit of armour, beside which the best ever worn by the most puissant of mediæval knights was clumsy in the last degree.

FIG. 3.—THE LORD OF THE WATER INSECTS, THE PLUNGER BEETLE *(DYTISCUS MARGINALIS)*.
The science of offence and defence has been completely mastered by this ruthless tyrant. Even the larva has a very serviceable pair of sickle-shaped jaws.

His weapons of offence consist of a most terrible pair of jaws, coupled with an array of suckers on the extremities of the first and second pairs of legs, so that, once in his grasp, the unlucky prey has not the slightest chance against its assailant.

Nor is the larva less voracious than the perfect insect; for, though a soft-bodied grub, it possesses a ferocious pair of sickle-shaped jaws, hollow from end to end, through which it sucks the juices of

snails or any weaker brother it can seize. A pair of ample wings, mysteriously folded up under the wing-cases, are ready to bear the *Dytiscus* from pond to pond at his pleasure. This beetle is one of a large family, and his cousins of various degrees of removal, and ranging downwards in size, are always to be found in the same situations and pursuing the same course of life.

Walking rather than swimming through the water, is a larger though far less powerful insect — the great Water Beetle (*Hydroüs piceus*) (Fig. 4) —falling a prey at times, it is said, to its more active neighbour, the *Dytiscus*. In colour he is black, and in point of diet mainly a vegetarian, though the larva resembles that of *Dytiscus* in general appearance.

FIG. 4.—STAGES IN THE LIFE CYCLE OF THE GREAT WATER-BEETLE *(HYDROÜS PICEUS)*: LARVA, PUPA, AND ADULT.

As usual in the insect world, the poor male is completely in subjection to his huge and energetic wife.

Abundant as are the beetles in every pond, they are rivalled, if not surpassed, in number by the "Norfolk-Howard" family.* Most conspicuous of these is the Water Boatman (*Notonecta glauca*) (Figs. 5 and 6), who may be seen floating at the surface of every piece of water, engaged, like the beetles, in taking in a fresh supply of air; but whilst the beetle is back uppermost, the bug prefers to swim with his back downwards—an arrangement which, however seemingly awkward from our point of view, is to the *Notonecta* an advantage, enabling it to attack its prey from beneath—a mode of assault which he is said to practise with success even upon small fish.

Unlike the beetles, too, the larval stage of the bugs is very similar to the adult, and individuals of all ages will be found together.

Still more plentiful is the nearly allied *Corixa* (Fig. 7), which can be easily distinguished from the Boatman, as he follows the normal mode of progression (*i.e.* back upwards), and descends from the surface as if going down a spiral staircase. The middle pair of legs are the longest, and are used as anchors, by means of which this insect may be observed holding on to the pebbles at the bottom, and giving at intervals a kind of spasmodic flip with his paddles. In amongst the weeds another bug (*Naucoris cimicoides*) will be found—a flat, oval, and rather soft-bodied little fellow.

By far the most curious-looking members of this interesting family are the Water Scorpion (*Nepa cinerea*) (Fig. 8),

* One Joshua Bug changed his name to Norfolk-Howard.

and his first-cousin the *Ranatra* (*R. linearis*). The former owes his name to the large size of the fore-limbs, which are carried straight out in front, like the claws of his namesake, and to the presence of a bristle-like tail. The body is oval, and not thicker than a sixpence. The middle and hind pair of legs are very slender, and by no means adapted for swimming; hence he dwells amongst the thick weed, seldom venturing into clear water, but, relying on his close similarity to a dead leaf, awaits with open arms the advent of the foolish water-creature that shall first pass within reach.

FIG. 5.—THE WATER BOATMAN (*NOTONECTA GLAUCA*).

Not content with swimming in the ordinary way, the Water Boatman prefers to lie upon his back.

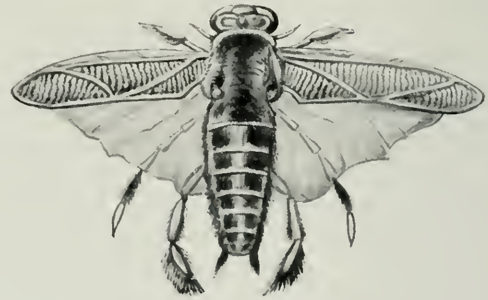


FIG. 7.—THE CORIXA'S IDEA OF PROGRESS IN LIFE IS THE SPIRAL.

He uses his middle pair of legs as anchors.

FIG. 6.—THE WATER BOATMAN CAN ALSO FLY.

The only thing in which, at first sight, the *Nepa* appears to resemble the *Ranatra* is the bristle-like tail. This, in reality, consists of two bristles placed close together. Down the inner side of each there runs a groove, so that when in juxtaposition they form a fine tube leading down to the cavity between the wings and the body, and the creature can therefore obtain a fresh supply of air without coming quite to the surface by simply extending the tip of this tube above the water. In other respects they appear very different, the *Ranatra* being as long and cylindrical as the *Nepa* is broad and flat. Closer inspection proves the difference to be in degree rather than in kind; and the more narrowly we compare them the more does the somewhat ludicrous notion seize us that originally they were identical, and were subsequently altered, the one by being passed under a mangle, whilst the other was pulled through the keyhole.

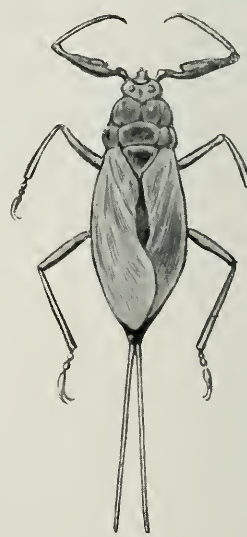


FIG. 8.—TIMID, BUT SLY: THE WATER SCORPION (*NEPA CINEREA*).

Skimming over the surface is another lanky individual, the Water Measurer (*Hydrometra Stagnorum*) (Fig. 9), perhaps

the most elongated of all the innumerable inhabitants of our pond.

Besides the foregoing, so to speak, permanent residents, there are some insects that spend a portion only of their existence under water. The common gnat is a familiar example of this class, to which also the May-fly and Dragon-fly (Coloured Plate) belong, all three passing the larval and pupal stages under water.*

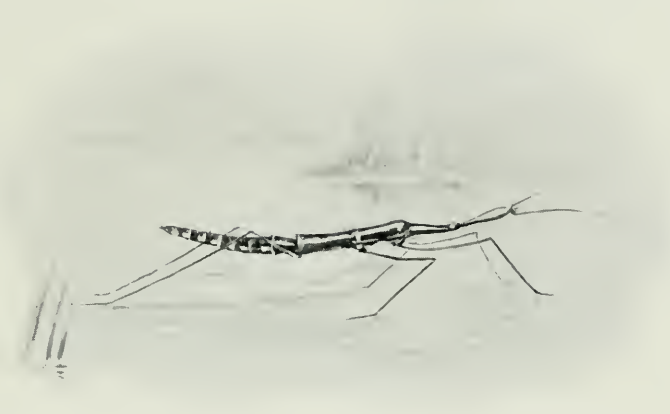


FIG. 9.—VERY THIN AND VERY NIMBLE: THE WATER MEASURER (*HYDROMETRA STAGNORUM*).

But it is time for us to pass from these rapacious individuals to speak about some of the more peaceful denizens. Gliding along at the surface of the water, shell downmost, we observe several different kinds of pond-snails. The commonest of these is the "Wandering Mud-snail" (*Limnæa pereger*) (Fig. 10, *B*), which is not only widely distributed—occurring throughout Europe, and ranging into Siberia and Tibet—but also most subject to variation according to the surrounding circumstances in which it is placed. Indeed, it is not impossible that an allied form (*Limnæa auricularia*) (Fig. 10, *A*) may be merely a very expanded variety of this same "Wanderer," though not yet acknowledged as such by authorities. The finest of our fresh-water molluscs is the Pond Limnæa (*L. stagnalis*) (Fig. 12), whose spiral shell measures nearly two inches in length, two-thirds being taken up by the last, or "body-whorl," as it is called. He is a famous aquarium glass-cleaner, but has an unfortunate habit of dying in some out-of-the-way corner of the establishment, the first announcement

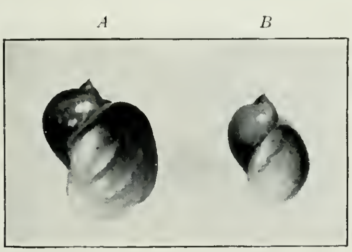


FIG. 10.—POND SNAILS.
A, *Limnæa auricularia*. *B*, *L. pereger*.

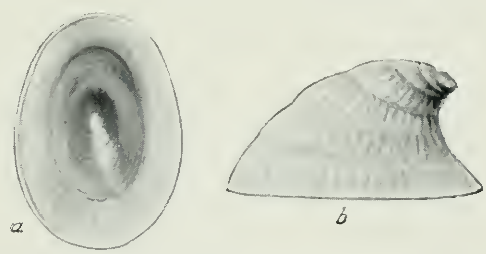


FIG. 11.—SHELL OF THE FRESH-WATER LIMPET. (*ANCYLUS LACUSTRIS*).
a, *view from below*; *b*, *side view*.

FIG. 12.—LARGE POND SNAIL (*L. STAGNALIS*).

* A most amusing account of the two last-mentioned is given in Kingsley's "Water Babies."

of his decease being the unwholesome state of the water.

In all the Limnæas the shell is very thin, semi-transparent, and horn-coloured; and the external surface, especially in *L. stagnalis*, looks as if it had been hammered all over. Then there is the fresh-water limpet (*Ancylus lacustris*) (Fig. 11) and the Coil-shells (*Planorbis*) (Fig. 13), varying in size from a halfpenny downwards, in which the shell, instead of being an ordinary spiral, is wound upon itself like a watch-spring.

FIG. 13.—COIL-SHELLS (*PLANORBIS CORNEUS* and *MARGINATUS*).

Crawling on the bottom is yet another snail, of very different appearance, proportionately shorter and dumpier than the Limnæas, and of a greenish-yellow tint, with brown bands. The peculiarity of the members of this genus (*Vivipara*) is that the eggs are hatched within the shell of the parent, the young escaping at about the end of two months.

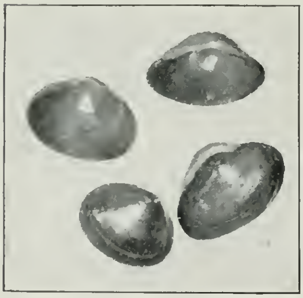


FIG. 15.—THE LARGEST FRESH-WATER COCKLE (*SPHÆRIUM RIVICOLA*).

If we descend into the mud at the bottom, the "fresh-water cockles" (*Sphærium* and *Pisidium*) (Fig. 15), and possibly the "fresh-water mussels" (*Anodonta* and *Unio*) (Figs. 16 and 17) will also await us. The *Sphærium* "draws out" of the mud during the summer months, and may be found climbing the water plants or floating near the surface.

FIG. 14. A GILL-BEARING SNAIL WITH A "LID" LIKE THAT OF A PERIWINKLE.

That delight of juvenile anglers, the common three-spined stickle-back (*Gasterosteus aculeatus*) (Fig. 18) is sure to be present in all his glory. Nor is he to be despised; he has a scientific fame, is a nest-builder, and not only does he build the nest, but also, arrayed in a coat of many colours, watches over and defends it against all comers, with a courage unequalled in one of his small size.

Here also is the Great Warty Triton (*Molge cristatus*), with black-spotted orange waistcoat; and his lesser relative, the common newt (*Molge punctatus*) (Fig. 21); whilst the eggs and tadpoles of the common frog and toad may be had in abundance during the spring months; but the life-history of the newts and frogs is a study in itself.

FIG. 16.—THE SWAN MUSSEL (*ANODONTA CYGNEA*).
This shell fish "hugs" the mire at the bottom of the pond and we must dive to get him.

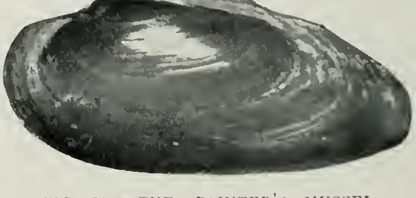


FIG. 17.—THE PAINTER'S MUSSEL (*UNIO PICTORUM*).

It would take a volume to describe the water spiders, water mites, leeches, and myriads of lesser fry that people the subaqueous forest ; and he who would make himself even superficially acquainted with the fauna of a pond must arm himself with a good net and attack the creatures in their weedy stronghold. A net on a long stick will do a great deal, certainly, but the surest method of proceeding is to detach the net from the stick and fasten it by four short cords to the end of a stout line and then, having weighted the end of the net with a bullet or two, and lined it with gauze to prevent the escape of the small specimens through the meshes, hurl it right out into the middle of the pond and drag it to shore through every possible patch of weed. The "net" result should then be shaken out on a level spot on the bank, the quarry captured, and specimens taken home for the purpose of identification and study.

FIG. 18.—WARM BUT NOT WATERTIGHT: THE STICKLEBACK BUILDS A NEST.

By going to work in this way specimens that might otherwise escape are dragged in and secured.

A careful examination of the gauze lining should be made between each haul, as small specimens, such as water-mites, several of the more minute shells, and larvæ, are sure to be found sticking to it.

At present we cannot do more than dip a wide-mouthed glass bottle into the water where the weed is thickest, and hold it up to the light to see if any of these lesser inhabitants are present.

There are some little whitish creatures skipping about with a jerky motion that has earned for them the name of water-fleas (Figs. 19 and 20). They claim no close relationship, however, to the *Aphaniptera*, being in reality crustaceans, and interesting as microscopic objects. Two or three water-mites, looking like small hairy-legged spiders, with red bodies, complete the list of visible animalcules. The rest must wait till we get home.

But stop! What are these green specks roving at will through the water? *Volvox globator*, the tiny revolving globe so sought after by the microscopists. It is rather capricious in its choice of locality and times of occurrence, and should therefore be secured whenever found, as it is one of the most beautiful objects imaginable under the microscope.

Another point of interest in connection with our subject deserves to be mentioned. Supposing a new pond to be formed at

some distance from any previously existing piece of water—how is it that before very long it becomes thickly populated? And what forms are likely to arrive first? Now, the air we breathe is full of small specks of dust called motes, as may be seen when a ray of sunlight is shining into a room. Many of these specks or motes are nothing more than the germs or eggs of the thousand and one animalcules so prevalent in all waters. As soon as these germs alight on water, development commences, and the matured individuals, by their rapid multiplication, speedily stock the new-found situation with life. The insects, of course, find their way thither on the wing. The beetles—especially *Dytiscus*—are great nocturnal fliers, plunging down at cock-crow into the nearest piece of water; hence their occasional presence in water-butts, or the durance vile of a roadside puddle. The newts and frogs, too, will travel by the overland route: but how do the snails

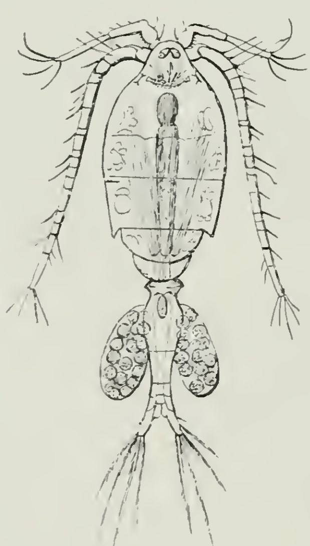


FIG. 19.—WATER FLEA (*CYCLOPS*) WITH EGG SACS.

get there? This has been answered by Mr. Darwin, who suspended the feet of a duck in an aquarium, where the eggs of fresh-water shells were hatching. Some of the young snails crawled on to these feet, and adhered so firmly that they could not be jarred off, though readily

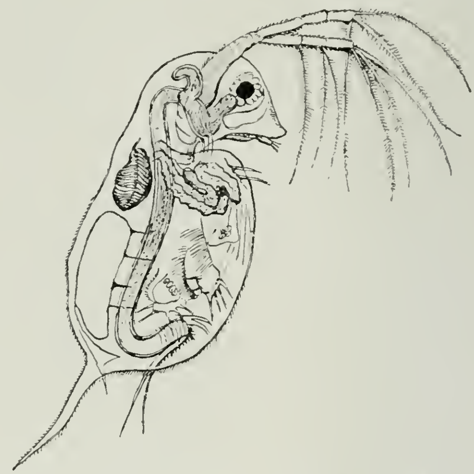


FIG. 20.—THIS WATER FLEA HAS NO CLAIMS TO BEAUTY, BUT HE IS LIVELY.

falling at a more advanced age. These young molluscs, when taken out of the water, survived in damp air from twelve to twenty-four hours, during which period a long journey could be made by the bird. The same observer also mentions that a *Dytiscus* was caught with an *Ancylus* firmly adhering to it; and were anyone to take the trouble of intercepting these beetles during their nocturnal excursions, they would doubtless be found to play an important part in thus distributing the smaller species of water-creatures. The transference of fish from place to place, without calling in the aid of the before-mentioned juvenile angler, is, however, a question that does not admit of easy solution at present, though very possibly their eggs are carried on the feet of wading birds, as the seeds of plants are known to be.

Enough has now surely been said, in even this brief space, to show that a pond, so far from being as devoid of interest as most people seem to consider, is in reality an inexhaustible source of both amusement and instruction. Amusement in watching the—to us, at all events—

curious behaviour of its inhabitants, either in a state of nature or when kept in an aquarium ; instruction, in systematically studying these various beings collectively, or as separate members of the animal kingdom ; or, when we consider their distribution, the abundance of some particular species in one locality, and its variety or absence in another ; or its prevalence at one season of the year and scarcity at another ; or again, in ascertaining the effect on them of the presence or absence of mineral matter—such as lime and iron —in solution in the water, with many other questions of a like nature too numerous to be detailed.

From the foregoing remarks it may be gathered that ponds are interesting—firstly, in themselves, their presence being due to physical causes, not merely in operation at the present day, but also in remote bygone ages ; secondly, on account of the various forms of life they contain. These alone are a life-long study, embracing as they do representatives of most of the zoological sub-kingdoms, from the back-boned amphibians down to the lowest forms of animal life, where they pass almost imperceptibly into the vegetable world ; whilst researches into their habits, economy, structure, and distribution marshal before us a host of interesting questions and numerous as yet unsolved problems.

FIG. 21.—THE GREAT WATER NEWT (*MOLGE CRISTATUS*), MALE, FEMALE, AND TADPOLE.

DEW AND HOAR-FROST.

DEW is a rarer phenomenon than is commonly supposed, for very often what is called a dew-drop on a close examination proves not to be dew at all. Ordinarily, dew is explained by referring to the deposition of moisture that occurs when a glass containing cold water is brought into a warm room, and although some such process as this takes place when a body of moist air passes over a surface whose temperature has been reduced. something more than this goes to the making of a real dew-drop. Similarly, hoar-frost is briefly dismissed by saying that it is frozen dew, but both as regards dew and its near relation hoar-frost there is a history that well repays investigation. Now there is no better way of making a few observations concerning dew than to use a few selected articles from the domestic china closet. By putting on a lawn such things as cups, saucers, plates, dishes, and glass tumblers, on any cloudless night, much interesting information may be gleaned as to the capricious way in which dew deposits itself. The observations, moreover, may be made still more complete if these objects are exposed on gravel paths and over different kinds of soil.

At a favourable season of the year this simple experiment would at once reveal the fact that some objects are much better collectors of dew and hoar frost than others; while a closer investigation would indicate that this was because the various objects differed as regards the rate at which they radiated the heat acquired during the day. The experiments of Dr. Wells, who was the first to study the subject systematically, were of a very simple and intelligible character, only instead of using china objects, or different coloured boards, such as some modern meteorologists have employed, he used small flocks of cotton-wool.

He first weighed out this homely material into parcels of ten grains each, and he then "teased" and loosened out the fibres of each parcel until it assumed the form of a flat circular flock, exactly two inches in diameter. These flocks of identical weight and size were then exposed to the open air in different ways and under varying conditions, and it was afterwards ascertained how much moisture had been deposited in any one of them during an entire night's exposure by again weighing the flock in the scales. In his next proceeding, he arranged two precisely similar flocks of wool, a little distance apart, upon the grass, and then sheltered one from the sky by a penthouse of cardboard, whilst the other was left without any covering above. In this case, after a night's exposure, the uncovered flock had increased 16 grains in weight, whilst the one screened by the cardboard had gained only two grains in weight. In order to make it quite sure that in this instance it was not rain which had fallen upon the uncovered wool to cause its increase of weight, he repeated the experiments in a modified form, by placing a circular cylinder of baked clay, 12 inches across, and 30 inches high, and open at the top, round one flock of wool, instead of covering it with the ridged pent-house. If rain were the cause of the load of moisture which the screened wool received it would clearly get to it on any still night through the roofless screen. But, as a matter of fact, the flock included within the open circular wall only received 8 grains of moisture, whilst

a companion flock upon the open grass received 16 grains. When one flock of wool was laid upon the open grass, whilst a second was placed close at hand upon a gravel walk, the wool upon the grass increased 16 grains, whilst the wool upon the gravel increased only 9 grains. Upon examining in connection with this experiment the actual temperature of the grass-plat and the gravel-walk, two and a half hours after sunset, it appeared that the gravel was sixteen degrees warmer than the grass. It was manifest, therefore, that the grass had distributed its heat into the air-space above much more rapidly than the gravel, and there could be no doubt that this was the proper interpretation of the deposit of the moisture upon the grass, and of its absence upon the gravel.

It may, indeed, be accepted as scientifically proved that dew is simply the moisture abstracted from the air by the rapid cooling of the bodies with which that air is in contact. Dew is less readily formed on cloudy nights, because the clouds overhead then act as heat-screens, very much in the same way as the paste-board roof and the baked clay wall in Dr. Wells' experiments. It is not formed on windy nights, because the drifting air then brings its own temperature to the radiating bodies, and prevents them from getting cooled as speedily as they would otherwise do. Under all circumstances, dew forms upon some bodies, such as wool and grass, and not upon others, such as gravel and mould, because in the one case those bodies are good radiators of heat, and cool very quickly under an unscreened sky, whilst in the other case they are bad radiators, and cool very slowly, notwithstanding their free and open exposure.

Photo: York & Son, Notting Hill, W.

FIG. I.—A PRETTY WINTER SCENE: HOAR FROST ON LONG GRASS.

It is the cold which is produced by the ground radiation at night which enables ice to be formed without any complicated apparatus even at Calcutta. Shallow pits are dug out in the earth two feet deep, and are filled with straw. Flat dishes of porous, unbaked clay, containing a small quantity of water, are then placed upon the straw, and left exposed to the sky through the night. The heat is, in con-

sequence, so rapidly radiated away from the water that it becomes frozen into ice. The straw occasionally descends to a temperature of 27° when the air is stand-

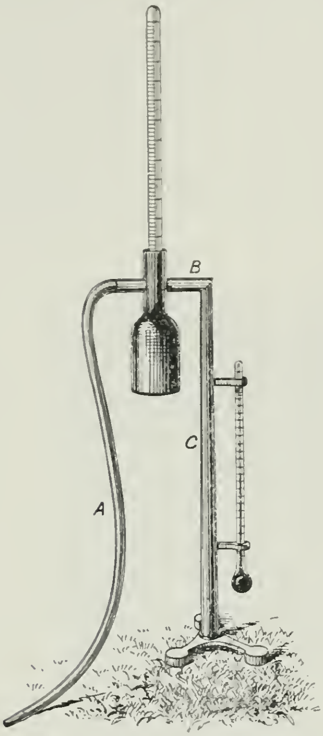


FIG. 2.—REGNAULT'S APPARATUS FOR OBSERVING THE DEPOSITION OF DEW.

A, a small flexible tube; B, bottle; C, hollow support of stand. A thermometer is fixed to C.

ing at 48° Fahr. above. Half a ton of ice is not unfrequently procured by this arrangement from a pit 120 feet long and 20 feet wide.

Whether dew is, or is not, deposited at any given temperature depends very much upon the amount of invisible vapour that is contained in the air at the time. It will be remembered that at each particular degree of temperature the air can sustain a certain charge of invisible vapour. At the freezing point of water it can hold a trifle in excess of two grains in each cubic foot, whilst at 60° Fahr. it can retain nearly six grains to the foot, and at 80° eleven grains. The slightest diminution of heat through radiation would suffice to cause deposits of dew at either of these temperatures in air charged with moisture up to these amounts. But a much greater depression of temperature would be required for the formation of dew under the circumstance of partial saturation with vapour at low temperatures than at high ones.

In all cases the temperature at which this deposition of moisture takes place is called the *dew point*; or, in other words, the dew point is the temperature below which any given body of air cannot be reduced without surrendering some of its moisture. In this respect the air may be likened to a sponge, for it has a similar capacity for absorbing moisture, and the dew point represents the squeeze that causes the moisture to be discharged. Numerous instruments have been in-

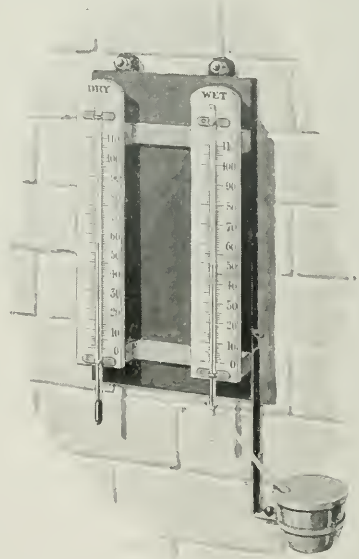


FIG. 3.—A WET AND DRY BULB THERMOMETER, I.E. *HYGROMETER*, EXPOSED.

vented for recording this critical temperature, and since they also tell what is the condition of the atmosphere as regards its humidity, they are called *hygrometers*. A very convenient instrument was devised by M. Regnault for the

direct observation of the temperature at which dew begins to form. This apparatus consists of a bright silver bottle, through the neck of which a delicate thermometer is introduced in such a way that its bulb is plunged into a small quantity of ether contained in the lower part of the bottle (Fig. 2).

A small flexible tube, *A*, attached to one side of the bottle, is continued on into a pipe which dips down beneath the surface of the ether inside. When this flexible tube is blown into by the mouth, the air first bubbles up through the ether and then escapes through the opposite side of the bottle, *B*, and through the hollow interior of the stand, *C*; but as it does so it carries a considerable charge of the vapour of the ether with it, and by that means lowers the temperature both of the bottle and of the thermometer, until dew begins to appear upon the bright surface of the silver. At that instant the thermometer shows the temperature at which the deposit occurs, and a glance at a second thermometer placed outside the stand tells what the temperature of the air is at that time, and consequently how many degrees that temperature would have to be depressed for the formation of dew.

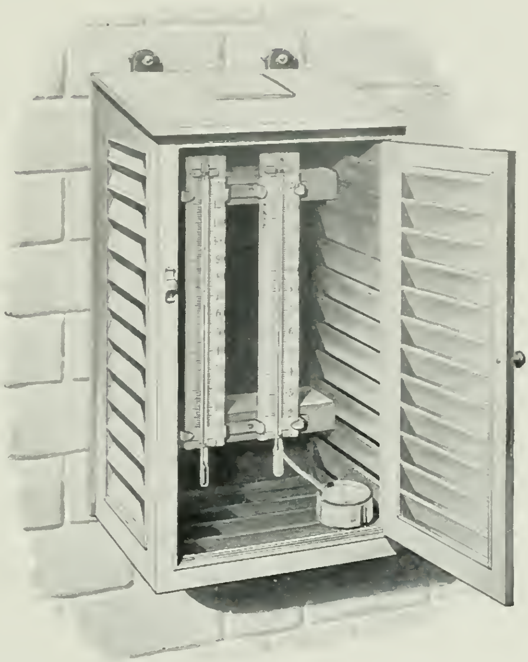


FIG. 4.—A HYGROMETER IN CASE.
The reading in this case is likely to be far more accurate than it is upon the exposed hygrometer.

This and similar hygrometers, however, entail a certain amount of manipulation, and for this reason they are not generally employed in ordinary meteorological work. The hygrometer most commonly in use is the dry and wet bulb instrument, this apparatus consisting of two thermometers side by side, the bulb of one being enclosed in a piece of muslin that is kept constantly moist by means of threads of cotton immersed in a small vessel of water (see Fig. 3). Now the drier the air the faster the evaporation from the muslin, and, since loss of moisture means loss of heat, the wet bulb records a lower temperature than its dry companion. The difference between the two readings indicates, therefore, the state of the atmosphere as regards its humidity. Tables have been compiled that show at a glance the dew point of the air in any given condition of temperature and moisture indicated by the two thermometers. Such tables are easily understood, and should, of course, always be used with the hygrometer, otherwise the true meaning of the readings recorded will not be revealed. The rate of evaporation from the wet bulb is, however, affected by the wind, and in order to protect it from this undesirable influence it is usual to hang the two thermometers side by side in a screen (Fig. 4).

Observations made by instruments of this class are of great practical importance, because they indicate beforehand the tem-

perature which may be expected to be the lowest likely to occur in the approaching night. When dew begins to form, it at once sets free a considerable quantity of latent heat which was before insensibly employed in keeping the water in a state of expanded vapour. This emancipated heat then acts in warming the air and prevents it from sinking to a still lower temperature. In this way, air surrounding the surface of radiating objects, such as the leaves of living plants, is kept alternately rising and falling in temperature close upon the degree of cold at which the dew is deposited for a considerable time. The radiating objects first grow a little cooler from the dissipation of their heat, then dew is deposited, and they are warmed by the latent heat which is in that way set free; and the two processes of slight cooling and warming alternately recur for some time. If, on a clear, still evening, dew is found to be deposited at a temperature of 44°, it is certain that no injurious frost will occur on the following night. But if dew is not formed until the temperature is reduced to 39°, there will most probably be sufficient frost in the night to injure delicate plants. The efficacy of the gardener's operation of covering up his plants in a cold season with matting and straw entirely depends upon the power which these coverings possess of preventing the radiation of heat from living structures. They act precisely in the same way as the cardboard screens in Dr. Wells' experiments.

But cold is not the only condition that is concerned in the formation of dew. There are, for instance, many points remaining for investigation as regards the origin of the moisture out of which the dew is fabricated. Commonly, most people believe that dew falls out of the air, but there are good reasons for believing that in reality it comes up from the ground. Certain experiments have been made by using painted trays one foot square and three inches deep, and inverting them over grass and different soils. These experiments, which were continued during a long period, showed that more moisture was collected on the under-side of the trays than on the top. From these and other considerations, therefore, it has been concluded that dew is formed by the vapour rising from the ground, and not so much from the vapour that falls from the air. Such experiments as these further indicate that it is not strictly correct to speak of a heavy fall of dew.

In this connection it may be noted that some meteorologists have shown that the drops of moisture often observed on certain plants are not dew-drops, although they are commonly so called. The poets, it has been pointed out, have in all ages sung many songs about the dew-drop, not knowing that they were singing about something very different. The large drops of moisture, for instance, to be seen on broccoli, turnips, and such flowers as poppies, are popularly called dew-drops, but in most cases they are really drops of moisture exuded by the plants themselves through their water pores. This also has been a subject of investigation, the leaves of certain plants having been kept under observation. Thus when the leaf of a plant is isolated by placing it in a receiver, the drops of moisture form quite as well as when it had access to the moisture in the air. If the roots of the plant are removed the drops disappear, while if the plant be supplied with water by means of an indiarubber tube the drops again appear. Plants, moreover, have been fed with coloured water, with the result that the exuding drops have also become tinted. It has also been observed that the plants that grow most vigorously are also those that develop the most drops. It is, then, on these grounds that the belief in large dew-drops has been discredited, for, as shown above, such drops have a very different origin from

the true dew, the drops of which are individually so small as to be almost invisible.

It is not possible to say how much water is deposited upon the earth in a year in the form of dew. Some meteorologists have estimated the amount at five inches of vertical depth, or about a seventh part of the moisture which is evaporated into the air. Some recent experiments, very carefully made at Walton-on-Thames by Mr. George Dines, seem, on the other hand, to indicate that the dew scarcely amounts to more than an inch and a half of water in the year. The quantity of dew which is supplied to the earth in most places in England very probably lies somewhere within the limits of these extremes. Whatever the exact quantity may be, it is, at any rate, enough to render very essential service in supporting vegetation through seasons of drought, when very little rain falls, and to justify the Hebrew Psalmist in speaking of it as a Heaven-sent blessing. In this connection it may be mentioned that stones are great collectors of dew. If, on a dewy morning, anyone will take the trouble to turn over some of the large flints lying in the fields it will generally be found that their under-sides are quite wet. This dew, moreover, when it is presently evaporated, does not pass into the air, but is returned to the soil. On account of this facility for retaining moisture the action of such stones is, from an agricultural point of view, not without its uses.

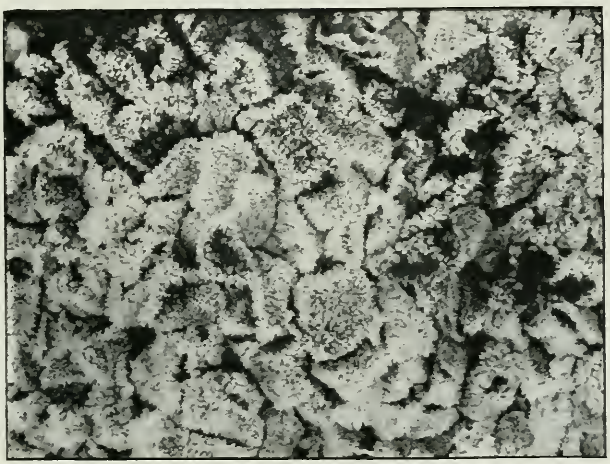


Photo: York & Son, Notting Hill, W.

FIG. 5.—HOAR FROST ON A HEAP OF GRANITE

The exceedingly beautiful appearance with which most of the inhabitants of England are familiar under the name of hoar-frost (Figs. 1, 5, 6, and 7) is nearly allied to dew. The white incrustation which at such times ornaments the landscape is, indeed, neither more nor less than frozen dew. It is dew deposited at a time when the dew-point of the air stands lower than the freezing-point of water, and when, therefore, the moisture which is abstracted from the air at once presents itself in the form of needles of ice. The ice spicules are arranged in a somewhat confused and indefinite way, on account of their intimate association with, and deposit upon, the surface of the radiating objects. The needles project from the frosted surfaces like the short, stiff hairs of a stubbly brush. They are most abundantly produced and most lengthened out wherever the radiation of heat is most energetically carried on, as it is at the points and sharp edges of serrated leaves, and each different kind of plant consequently has its own pattern of frosting. Hoar-frost is very rarely seen on smooth, rounded surfaces, and it never appears where radiation is prevented. Screens expanded above and around are, on this account, quite as effective in preventing the occurrence of hoar-frost on plants as they are in obviating the deposit of dew.

But the most interesting thing as regards hoar frost is the irregular way in which it appears to select the objects on which to paint its frosty pictures. Further, when the frost is deposited the spicules appear to grow in a very erratic manner. Both as regards the objects selected and the manner of growth there are, however, certain well-recognised circumstances that govern the one and the other. In the first place, the objects that collect the greatest load of hoar frost are commonly those that have the best view of the sky, for in such a situation they are more readily cooled down to the required temperature. Cooled surfaces, indeed, are Nature's plates, on which are etched an endless variety of frost pictures. Anything, therefore, that retards radiation will hinder the formation of hoar-frost. Hence it is that trees, by retarding the radiation of heat from the grass beneath them, prevent hoar-frost from forming. Away from this protecting canopy the icy spicules may perhaps grow apace. Beneath trees and bushes, for instance, little hoar frost is to be looked for, although the upper sides of these objects may at the same time be covered in a glittering white mantle. Differences, therefore, as regards the rate of cooling explain the curious contrasts to be observed on a frosty morning.

As regards the causes which promote the growth of the frost pictures, it is to be remarked that at any given moment the vapour in the air has a pressure or tension that varies with its temperature. Just in the same way, therefore, that water runs from a high to a low level so the vapour in the air is continually condensing or running from places where the tension is high on to surfaces where the tension is low. Now, it has been discovered that the tension of the vapour over an ice surface is lower than it is over a water surface at the same temperature. Supposing, therefore, that a filmy deposit of hoar frost has fluttered down on to a fern frond, the tension over this icy deposit is lower than that of the vapour in the air around it. The result is

Photo: York & Son, Notting Hill, W.

FIG. 6.—A TYPICAL WINTER SCENE: BEECHES MANTLED IN HOAR FROST.

that as soon as the air touches the leaf it equalises the tensions by yielding up some of its moisture, which, by the alchemy of the frost, is promptly transformed into a delicate ice-crystal.

It is, moreover, well known that in favourable circumstances water may be reduced below its freezing point without actually congealing. The vapour in the air may at times be in this condition, the atmosphere under such conditions being said to be *supersaturated*. It is not surprising, therefore, that with such a load of vapour the air is easily robbed of its watery supplies, so that should it float against a suitable surface a touch is sufficient to cause the vapour to solidify as hoar frost. Of all the forces most active in building up a heavy deposit of hoar frost this is probably the most effective, and to this agency is due the fact that hoar frost accumulates sometimes even on the sides of objects that are turned towards the wind.

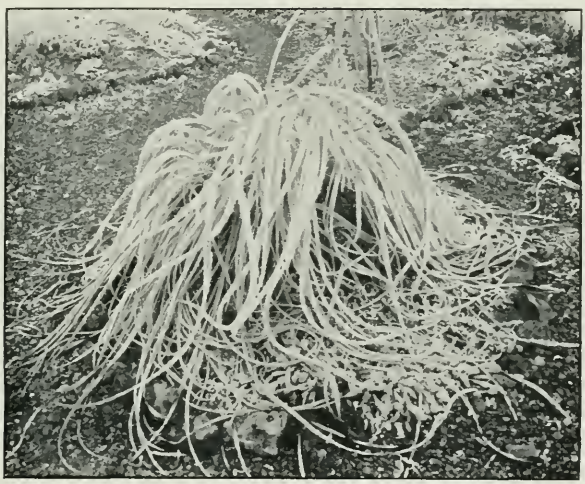


Photo: York & Son, Notting Hill, W.

FIG. 7.—HOAR FROST ON PAMPAS GRASS.

THE WIZARD ELECTRICITY.—V.

WIRELESS TELEGRAPHY: HERTZ-WAVE SYSTEMS.

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THE recent successes in transmitting intelligence over long distances without connecting wires are largely the outcome of the epoch-making experiments by which the great Heinrich Hertz startled and enthralled the scientific world in 1887–8. Up till then the "action-at-a-distance" theory had prevented advance in Germany, whilst those of our own physicists who gave attention to the subject were engaged mainly with earth induction and induction experiments. Following the wonderful mathematical deductions of Clerk Maxwell, Hertz was led to investigate methods of setting up and propagating electrical disturbances in the ether—that weightless, all-pervading fluid which fills space and is around and between the ultimate particles of all bodies, and by the vibrations of which light is transmitted to us from the sun. In the Hertz researches the *condenser* plays an important part. It consists of two conducting surfaces with a non-conductor or *dielectric* between. The Leyden jar is the commonest type of condenser, but very large condensers of special form are used in wireless work. The condenser may be charged to a higher and higher *potential* by holding one knob or terminal to the prime conductor of an electric machine, the other terminal being connected to earth; or one terminal may be connected to the positive pole of an electric generator, the other to the negative pole; or a Rumkorff coil may be employed. The higher the "potential" of the condenser the more is the "dielectric" strained, the insulating qualities of the air between the terminals finally breaks down, and a spark passes. This discharge—especially if an *aërial*, or vertical wire projecting into the air, be used—has the effect of causing oscillatory motion in the ether, which is carried to a distance, like waves in a calm sea, only that the waves in this case are peculiar and different from those in air or water. In fact, the discharge of a highly-charged condenser and aërial, say in England, causes a "splash" in the ether which may be detected in America if the disturbance be only great enough. Hertz called his apparatus for producing this disturbance an *oscillator*: the development of the modern oscillator is shown in Fig. 1. It may be stated, in passing, that the shorter and dumpier the form of oscillator the quicker the vibrations produced by its discharge None of these arrangements, however, will give rise to waves of the high frequency of light waves; indeed, Hertz-wave signalling employs a much lower frequency and greater wave-length than ordinary heliography, but the rate of propagation of the disturbance is the same. Thus Marconi's message from Nova Scotia travelled to England with the velocity of light, or, in other words, took less than $\frac{1}{60}$th of a second to accomplish the journey. Hertz made many experiments on etheric vibrations, and showed that they might be detected at a distance. His detector, or *resonator*, was a nearly complete ring of round wire, like an anchor ring, $13\frac{3}{4}$ inches in diameter, with a minute space or air-gap in it. Ether waves from the oscillator falling on the ring—especially when the latter was held

with its plane in a certain direction—set up electric oscillations in the ring which, if the tuning or *syntonising* of the two circuits was good enough, increased till they finally burst across the small air-gap, causing a minute spark. In modern wireless telegraphy the condenser still plays an important part, but the charging is usually done either by a Rumkorff coil or an *alternator*. The Rumkorff coil (so named after its inventor) consists of a core of soft iron wires of considerable diameter fixed into discs of the same metal. Round this core is wound the primary coil of insulated copper-wire, say 1 to 2 millimetres in diameter, with the secondary coil of specially insulated *fine* wire wound outside the primary. The secondary coil is of great length — in large coils as much as *ninety-four miles* of wire being employed, but in coils giving a 10-inch spark, such as are common in wireless transmitters, seventeen miles will do. The primary coil has usually a battery and condenser in its circuit, as well as an interrupter or *break*, which in coils made in England usually consists of a strip of iron like the trembler of an electric bell. The interrupter causes the current in the primary coil to be interrupted, and the sudden starting and stopping of this current gives rise to induced currents of much higher potential in the secondary,

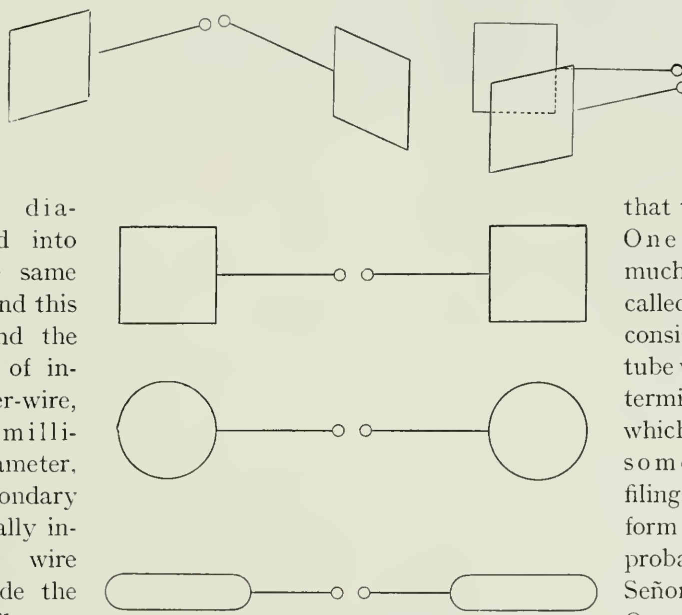


FIG. 1.—THE DEVELOPMENT OF THE MODERN "OSCILLATOR."

"The shorter and dumpier the 'oscillator' the quicker the vibrations."

which is connected to the spark-knobs. The pressure or potential required to give a spark of known length is obtained, approximately, from the rule—3,000 volts per millimetre of spark. Thus a 10-inch spark requires in the secondary a pressure of $3{,}000 \times 25{\cdot}4 \times 10 = 762{,}000$ volts.

A modern induction coil, such as that used by Mr. Marconi, is shown in Fig. 2. The modern *detector* of electric oscillations is very different from that used by Hertz. One form, now much employed, is called a *coherer*, and consists of a glass tube with two metal terminals, between which are placed some fine metal filings or dust. This form of detector is probably due to Señor Calzeechi Onesti, of Fermo, and Professor Branly, of Paris, but has been improved and used for Hertzian-wave telegraphy by Mr. Marconi, Sir Oliver Lodge, and others. The Marconi coherer is shown in Fig. 3. Two silver plugs are inserted in a glass tube from which the air is exhausted. The small space between the plugs tapers slightly, and is partly filled with filings consisting mainly of nickel with a small percentage of silver. These filings are usually non-conducting, but, when ether-waves fall upon the wire to which one terminal of the coherer is attached, the filings become conducting and allow a minute current to pass. The

coherer is then tapped by an automatic tapper to restore it to its original state, when it is ready to receive a new impulse.

The way in which the ether waves are radiated and received will be gathered from Figs. 4 and 5, in which is given diagrammatically the earlier arrangement adopted by Mr. Marconi. E is the elevated wire or "aerial," which is a feature of most Hertz-wave systems. This aërial is cut, and in the space thus provided is inserted the spark-gap, G, of a Rumkorff coil, the primary circuit of which has the usual battery and interrupter with a key, by which a longer or shorter series of impulses may be sent. The receiving circuit is equally simple, and consists of the aërial, one end of which—as in the transmitting apparatus—is connected to earth. The aërial has a space in it in which is the coherer, C, and a relay, R, with a single cell, B. The relay is able, with the help of the coherer, in ordinary circumstances to just overcome the tendency of the cell to send a current round its electro-magnet coils. When the ether vibrations are received through the aërial, E, the coherer becomes a conductor and transmits a feeble current; the balance of the relay circuit against the cell is upset; and the cell sends its current round the coils, attracting an armature and closing the circuit (not shown) of an auxiliary and stronger battery, in which is the Morse printer or other recording mechanism. This simple arrangement of transmitter and receiver was found to be effective only for comparatively short distances. Mr. Marconi introduced the transformer, condensers of great capacity, an alternator to charge the same, and many other improvements for longer distances.

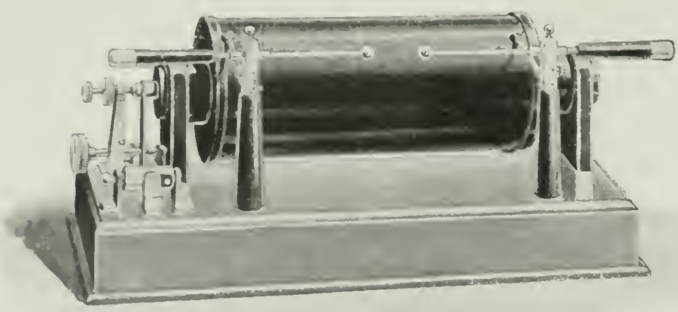


FIG. 2.—A MARCONI 10-INCH INDUCTION COIL.

There are 17 miles of fine wire in this "coil."

We generally associate the name of Marconi with all telegraphy of the kind herein described, and forget that there have been other successful workers in the field. But Marconi was the first to show us what wireless telegraphy really could do. Guglielmo Marconi, a young Italian, now twenty-seven years of age, came to England in 1896. He had previously made experiments at Bologna, and brought with him to England a patent which has been the subject of some discussion. He was, however, possessed of what is far more valuable than any patent—indomitable perseverance and a thorough belief in the ultimate success of the system. Mr. (now Sir W.) Preece, then electrical engineer to the Post Office, welcomed Mr. Marconi, and lent his

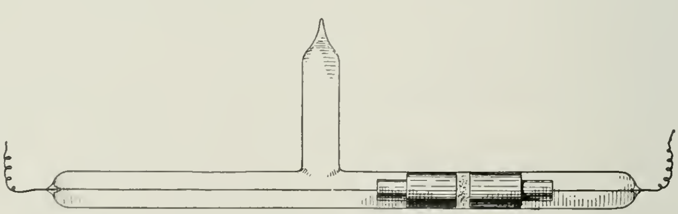


FIG. 3.—MARCONI COHERER.

Two silver plugs are inserted in a glass tube. The space between the plugs is partly filled with silver and nickel filings.

aid in the earlier exper.ments, which were carried out first on the roof of the General Post Office, London, later at Salisbury Plain and between Lavernock Point and Flat Holm in the Bristol Channel. Success, though not absent, was not easily wooed, and on May 11th and 12th, 1897, it seemed to some onlookers as if the fate of Marconi telegraphy hung in the balance—the experiments failed. An inspiration, such as comes to the true genius, saved the situation. On the 13th the receiving apparatus at Lavernock Point was carried down to the beach, and the vertical wire, or aerial, was lengthened by 60 feet, making it 150 feet n all. The result was now a success, and Professor Slaby, of Charlottenburg (author of the Arco-Slaby system), who was present, describes graphically the painful suspense of the first few minutes after the alteration of the aerial, and the feelings of the spectators when the Morse instrument was seen " visibly printing the signals borne to it by the mysterious ether from the island station scarcely visible in the distance."

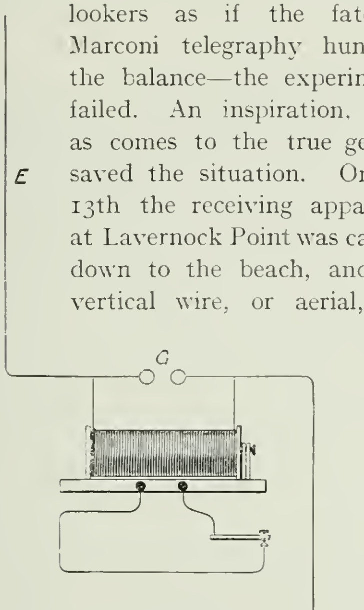


FIG. 4.—HOW ETHER WAVES ARE GENERATED.

E, elevated wire, or aërial. G, spark gap.

Many modifications and improvements have been introduced by Mr. Marconi into his apparatus, but what the actual arrangements are which he now adopts for transatlantic work it is impossible to say, as the matter is kept very secret. We know, however, that for long-distance work the coherer is replaced by the magnetic receiver. This apparatus is based on the decrease of *magnetic hysteresis* (a kind of magnetic inertia), which takes place in iron when exposed to Hertzian vibrations. In the apparatus referred to, two wooden pulleys, rotated by clockwork, carry a band of iron wires, the band at one place passing inside a coil which is in the circuit of the aërial. Opposite this coil are two magnets, which magnetise the band as it passes them, and, owing to magnetic inertia, this magnetised condition persists for some distance beyond the coil in the direction in which the band is moving. The ether waves from the receiving aërial, however, counteract the hysteresis effect, and a current is induced in an outer copper coil connected to a telephone, this induced current giving evidence of itself by repeating in the telephone the signals sent from the transmitting station, perhaps 2,800 miles away. This receiver was employed, I believe, in reading the message sent from President Roosevelt

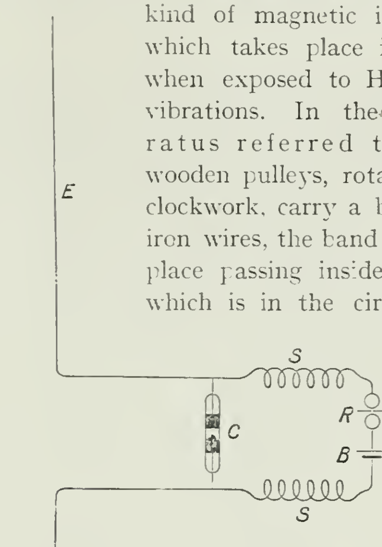


FIG. 5. — HOW ETHER WAVES ARE RECEIVED.

E, aërial; C, coherer; R, "relay," with its single cell, B; S, S, coils.

to the King in January, 1903. A view of the Poldhu Station at which it was received is shown in Fig. 6.

A description of the other arrangements adopted would lead to too many technicalities, but it may be mentioned that some important features are the form of aërial as shown in Fig. 6; the use of condensers of very great capacity, with oscillation transformers giving a very high potential, and a peculiar form of key by which the signals may be sent; also the use in the receiving circuit of the split transformer or *jigger*, the secondary coil of which is divided and has a small condenser between the portions. These and other improvements, carefully thought out by Mr. Marconi and Mr. Fleming, have rendered possible communication without connecting wires over distances once considered quite impracticable. The difficulty in causing the ether waves to surmount the hill of water 150 miles high which lies between Cornwall and America may readily be conceived, and it may be stated in passing that in all probability this is not possible over land, at least with present apparatus. One great feature of the system is the possibility of keeping in touch with a moving object such as a ship, and many vessels, both of the Navy and Mercantile Marine, have now been fitted with wireless apparatus by the Marconi Company. The interior of the signalling cabin of a ship recently so fitted (the s.s. *Minnetonka*, of the Atlantic Transport line) is shown in Fig. 7.

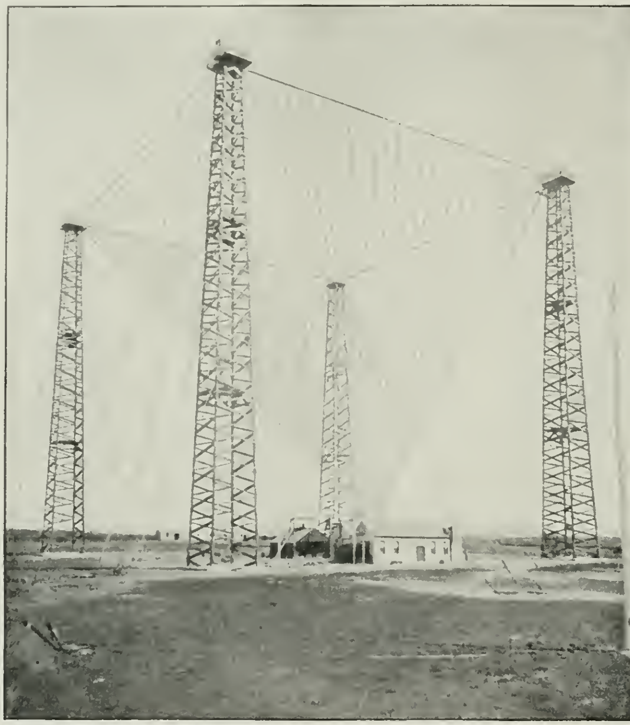


Photo supplied by the Marconi Wireless Telegraphy Company.

FIG. 6.—THE POLDHU WIRELESS TELEGRAPHY STATION.

The towers seen in the picture are upwards of 140 feet high, and they are connected with a lattice-work of wires or aërials.

This promises to be the most successful field for wireless telegraphy in the future.

The saving of human life, vessels, and perishable cargo which may be effected will, before very long, render it incumbent on owners and consigners to see that no ship leaves land on an important voyage without a wireless telegraph outfit.

The work of Dr. Lodge in connection with telegraphy has already been referred to. He and Dr Muirhead are the patentees of many devices which have contributed to success in this field, and the Lodge-Muirhead system has recently attracted some attention. This apparatus has that finish, solidity, and compactness, with provision for renewal of parts, characteristic of the best British cable work. Combined with this, there is said to be great simplicity in manipulation, with the smallest chance of derangement or injury. The system has not been tried over great distances, but up to sixty or 100 miles it has more than fulfilled the expectations of its designers. A coherer (the name is due to Dr. Lodge) is used as the receiver in this system, and whilst for long distances other forms of receivers in which a telephone is employed may be better, the coherer has the great advantage that by its use a *printed record* is possible. Those who have had experience of the system tell us that its special characteristics are as follows :—

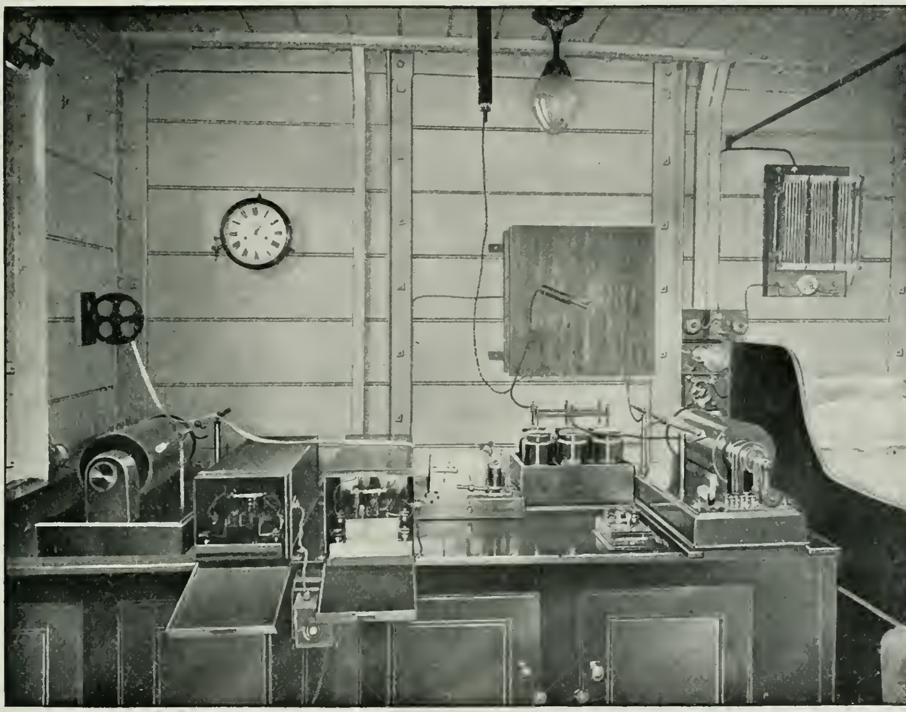


Photo supplied by the Marconi Wireless Telegraph Company.

FIG. 7.—WIRELESS TELEGRAPHY IN MID-OCEAN : THE MARCONI CABIN ON THE S.S. *MINNETONKA*, OF THE ATLANTIC TRANSPORT LINE.

A ship at sea need no longer be isolated. She need never lose "touch" with the land in calm weather.

(1) A coherer which is very sensitive. constant in action, and requires no tapping or de-cohering.

(2) No relay, the siphon recorder being used to print the message received ; this avoids complication and expense, whilst increasing the speed of signalling.

(3, and subordinate to the others.) The use of a very simple and effective form of

interrupter by which the frequency can be varied at will by merely turning a screw.

(4) The provision of an automatic transmitter by which even the unskilled may send perfectly clear and well-spaced messages.

Many of the details of circuits, etc., are of too technical a nature for description here,* but some of the principal features may be referred to.

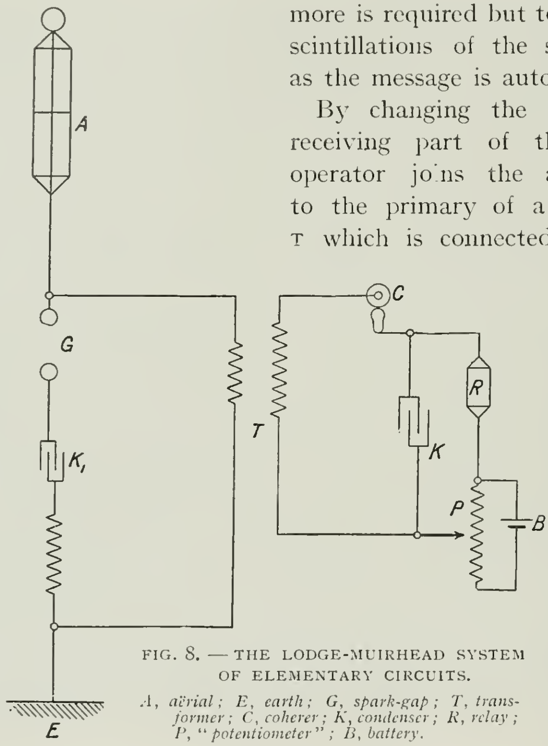


FIG. 8. — THE LODGE-MUIRHEAD SYSTEM OF ELEMENTARY CIRCUITS.

A, aërial; E, earth; G, spark-gap; T, transformer; C, coherer; K, condenser; R, relay; P, "potentiometer"; B, battery.

In the transmitting circuit there is the usual aërial, but with a variable wire-cage arrangement used mainly for tuning, a spark-gap with a capacity at its lower extremity, and the earth or earth capacity. There is a 10-inch spark induction coil of special form, the primary of which has a sending battery consisting of a box of secondary cells in its circuit. The current in the primary is interrupted by an ingenious apparatus which consists of a bent piece of stout aluminium wire, the vertical end of which is sharpened and dips into mercury, or is lifted out of it by a coil actuated by two post-office sounders acting reciprocally, and technically termed a *buzzer*. The spark apparatus consists of two vertical cylindrical brass pillars with rounded ends. The automatic transmitter is extremely interesting. A novice wishing to send a message sits down, and with his Morse alphabet before him punches his message by a series of blows on two little buffers, paying no attention to the spacing, which usually gives the greatest trouble to the beginner. The message comes out punched and perfectly spaced on a moving ribbon, which is then led into the proper apparatus. The sending switch which automatically short-circuits the coherer having been closed, nothing more is required but to sit and watch the scintillations of the sparking apparatus as the message is automatically sent out.

By changing the plug over to the receiving part of the apparatus the operator joins the aërial A (Fig. 8), to the primary of a little transformer, T which is connected to the steel disc of the coherer, C. This steel disc has a sharpened edge, which dips into mercury. The disc is rotated by clockwork, and on its upper portion rests a little pad containing oil. Thus the disc goes into the mercury with a film of oil adhering to it; this oil acts as a non-conductor until acted on by Hertzian-waves from the distant station, when it immediately becomes conducting, allowing a current to pass through the mercury to the siphon recorder, R, which is deflected for a shorter or longer period to represent a dot or a dash on the Morse code. As another portion of the disc with its oil film immediately comes into contact with the mercury, no de-cohering is required. The coherer is very reliable and rarely gets out of order.

The siphon recorder is really a very fine tube of glass from which ink squirts on a

* They are fully given and illustrated in the writer's little work on "Wireless Telegraphy," now in the press.

moving paper-ribbon. The siphon is attached to the moving coil of a sensitive *galvanometer*, and the latter can be arranged to ring a call-bell if required. So sensitive are the coherer and recorder that even dust collecting on the spark-knobs of the transmitter can be detected in the record printed.

In addition to the above the receiving circuit includes the condenser, K, shunted across the terminals of the recorder, as well as the *potentiometer*, P, to keep the potential at the recording mechanism of the required amount

duced by other workers will be gathered from Fig. 10, in which the receiving circuit of the *Arco-Slaby* system—one of the most successful of the continental systems—is depicted in outline. A is the receiving aërial, M a coil of special form—probably intended to introduce inductance equal to that of wire of one quarter the wave-length. The received impulses, wh ch are here a maximum as regards amplitude, reach the coherer, F. There is also a condenser inserted parallel to the cell, P, and re ay, R. In fact, the condenser plays an mportant part in the receiving

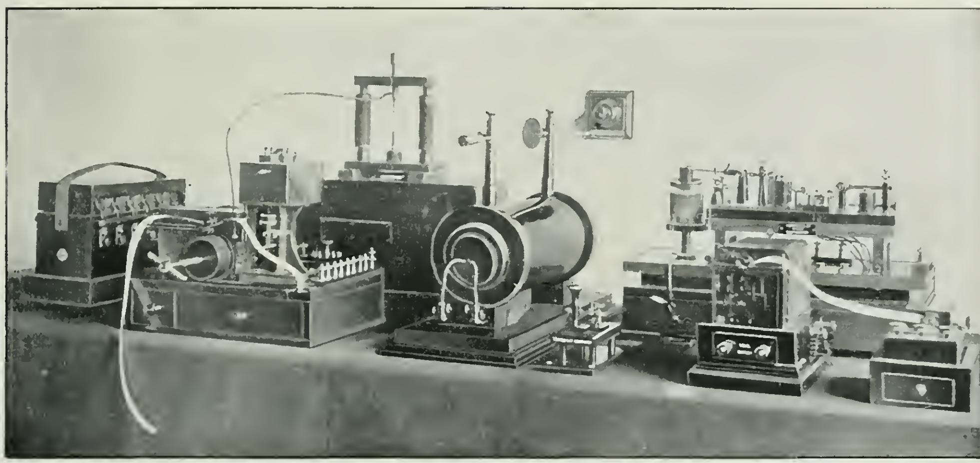


Photo supplied by Dr. Muirhead.

FIG. 9—COMPLETE OUTFIT AT A SENDING AND RECEIVING STATION: LODGE-MUIRHEAD SYSTEM.

A complete station outfit is shown in Fig. 9: the automatic transmitter to the right, induction coil with sparking apparatus in the centre, with the change-over plug or switch attached to the latter; whilst on the left are the coherer and siphon recorder, with the source of energy (a box of secondary cells) on the extreme left.

The recorder, S, and coherer disc, C, can be better seen in the enlarged view shown in Fig. 11.

Whilst England has been the home of research in this subject for many years, inventors in other countries have not been idle. Some of the modifications intro-

as well a the transmitting circuits of modern installations. It exercises an important influence in tuning the circuits. The transmitting circuit in this case contains a battery or other generator, a coil or transformer with an aerial having spark-balls giving a powerful spark. A complete station outfit for low-tension work is shown in Fig. 12, in which the inductor or induction coil is shown high up on the wall, a condenser at the back, a turbine interrupter on the table to the right, and a Morse machine.

One of the most interesting stations fitted with the apparatus of this system

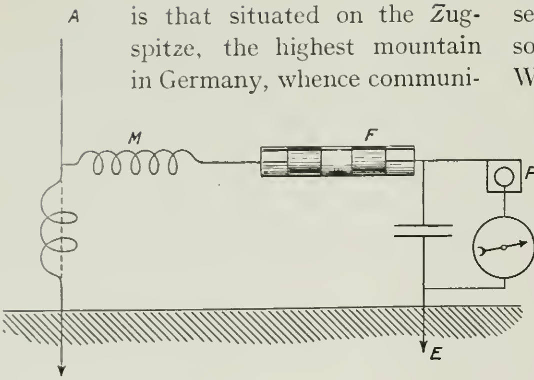


FIG. 10.—RECEIVING CIRCUIT: ARCO-SLABY SYSTEM.
A, aërial; M, coil of wire; E, earth; F, coherer; P, potentiometer; R, relay.

is that situated on the Zugspitze, the highest mountain in Germany, whence communication is kept up with a station 2,000 metres (6,560 feet) lower down.

Respecting the other great German system — that due to Dr. Braun (the Braun, Siemens, and Halske system)—space does not admit of an adequate notice. In it the impulses are received in a closed circuit, the lower extremity of the spark-gap not being earthed, and the system has many interesting and important features. Wireless telegraphy is destined to play an important part in modern warfare, hence the field-equipment of the last-named system shown in Fig. 13 is very interesting.

America has recently come to the front in this matter. The system here described is the product of Dr. Lee De Forest and Professor C. E. Freeman. It has, I believe, been adopted after severe tests by the United States Government for the army and navy. The system has many features in common with those already referred to. A transformer is employed at the transmitting station to raise the potential, giving a longer spark and more violent discharge. There is a suitable key for sending out proper trains of impulses, so as to form signals on the Morse code. When the key is held down the discharge from the large condensers across the spark-gap gives rise to rapid oscillations of the ether, which travel with the velocity of light till they meet the receiving aërial, the length of time the key is depressed determining whether the signal is received as a dot or a dash. The receiving aërial is connected through a transformer to the receiver, or *responder* as it is called in America, which consists in this case of two small electrolytic cells of special form containing a fluid, probably mainly glycer ne and water. The electrolytic action has the effect of building up chains of particles from *anode* to *kathode* across the cell; the incidence of the oscillatory impulses from the aërial, however, breaks up the chains and renders the cell less conducting, the result being a click heard in the attached telephone. A dot comes as a short series of clicks, a dash as a long series. The key at the sending station in this or Marconi's, or any long-distance

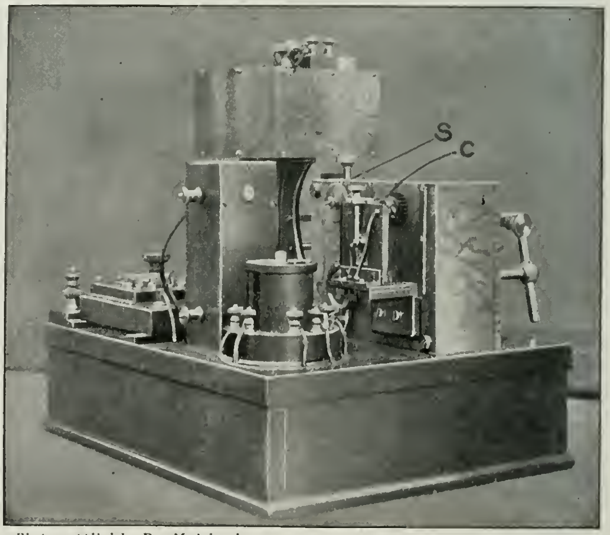


Photo supplied by Dr. Muirhead.

FIG. 11.—RECEIVING APPARATUS: LODGE-MUIRHEAD SYSTEM.

system, must be of peculiar construction, owing to the high pressure and large power radiated. The dots are distinguished by cracks like rifle shots, each dash by a roar like a Maxim gun. In Fig. 14 (from a photo kindly sent to me by Dr. Lee De Forest) the apparatus of a transmitting station are depicted; to the right is the key, a variable inductance or resistance in the centre; the oil transformer and spark apparatus lie to the left.

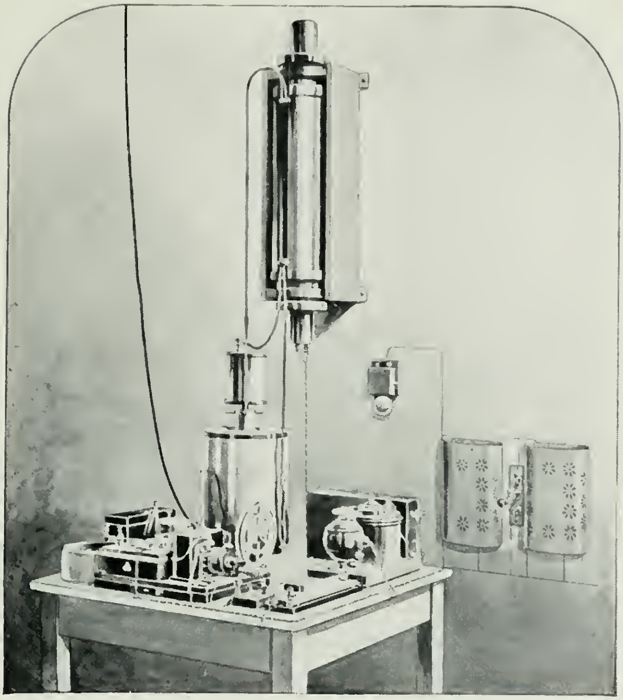


FIG. 12.—COMPLETE OUTFIT FOR WIRELESS TELEGRAPHY: ARCO-SLABY SYSTEM.

(By permission of Allegemeine Electricitats Gesellschaft, Berlin.)

American papers inform us that the De Forest Company either have erected or intend to erect many stations—the largest at California, with others at Manila, Honolulu, Hong Kong, etc. The distance from Manila to Hawaii is 3,500 miles, that from Hawaii to California 2,200 miles. Stations at Key West and other places are intended to form a complete chain across America

FIG. 13.—GERMAN ARMY WIRELESS FIELD EQUIPMENT: RECEIVING A MESSAGE.

(By permission of the Gesellschaft für Drahtlose Telegraphie, Berlin.)

and the Pacific. Should these long distances be successfully negotiated, Dr. De Forest may claim a place in the front rank in regard to wireless enterprise at the present time. Like Mr. Marconi, he is young—only twenty-nine years of age.

Of the future of this wonderful system of communication who can predict? It may be that soon the earth will be girdled by a complete system or systems of stations, and that all nations may thus be linked in a community of purpose and interest—let us hope for universal advancement and peace.

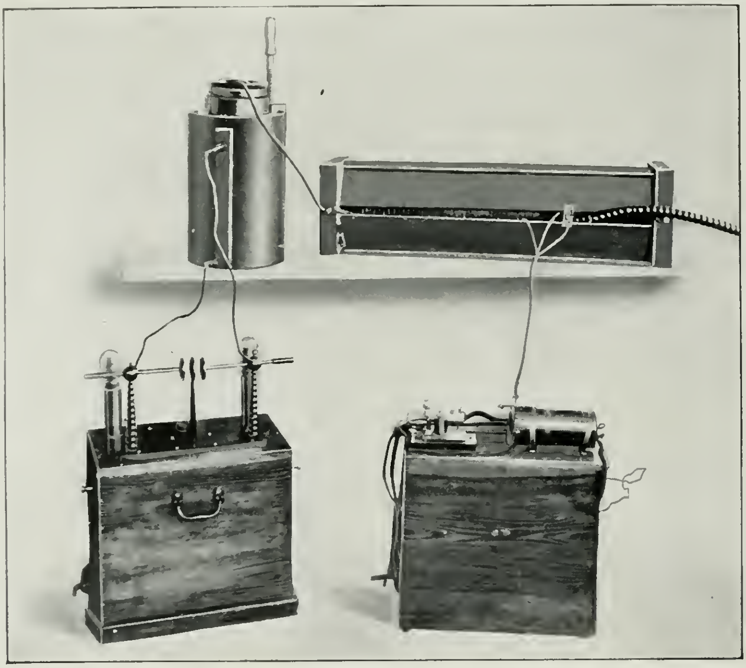


Photo. Harrison & Co., Jersey City, N.Y.

FIG. 14.—APPARATUS BELONGING TO THE DE FOREST SYSTEM.

(By permission of the De Forest Wireless Telegraphy Co.)

THE CURIOSITIES OF DIGESTION.

By Dr. ANDREW WILSON, F.R.S.E.

ONE of the sharpest lines of separation which can be drawn between the world of living things and that which comprises non-living things may be found in the fact that the former all demand their daily "bread." There exists what we might term a constant demand on the part of animals and plants for food. That nutriment lacking, life invariably comes to an end. The geranium growing in a pot has to be fed, otherwise its existence would speedily terminate. Our geranium requires to be supplied with minerals contained in the soil, with ammonia and with water. The last item is certainly the most important both for animals and for plants. There is no condition more fatal to a plant than dryness of its tissues, and the animal may be said to be practically in the same position. We may take it for granted then that, whilst crystals and other inorganic things grow by the addition of particles to their outside surface, or the process known as *accretion*, living things exhibit a very different characteristic in respect to their increase, for the animal or plant takes from the outer world matter which is more or less unlike itself. It *assimilates* this matter—that is to say, in plain language, it converts this material into itself. Hence we see another striking difference between growth in the non-living and growth in the living universe. The process of digestion is the one through which this work of assimilation is practically carried out. We might define it, as I have said, by asserting that its object is to convert our food into ourselves. That this is true a very slight consideration will be sufficient to show. A man eats a mutton chop for his lunch. Before many hours have passed that which was sheep has become transubstantiated into that which is man. That this process is necessary is obvious, seeing that unless our food became part and parcel of us, either through affording material to build up our tissues or by reason of its giving us energy or the power of doing work, it would be of no value to us. Digestion therefore appears as a highly important process in view of the fact that it represents the means whereby our bodily income, derived from the outer world in the shape of food, is made available for all the wants of our frames.

The purposes to which food is devoted in the body may be briefly summed up by stating, first, that it is the material out of which our bodies are built up. It therefore supplies the matter necessary for growth. In the second place it is required in order that the wear and tear of our tissues incidental to the work of life may be duly repaired. In the third place food supplies us with the power of doing whatever work we discharge in the world, whether this be muscular work, or, on the other hand, work of an intellectual kind. We may in this sense, indeed, compare the body to a locomotive engine, which presents two aspects to the person who considers it. First, the engine has to be built and constructed; second, it has to be supplied with materials, out of which it develops its energy, or the power of performing the work it is intended to do. The living body presents exactly the same relationship to the outer world with respect to its food.

Digestion is often popularly spoken of as a process whereby our food is converted

into blood. Now this definition is hardly correct. Our food is not precisely converted into blood—which, of course, is the common currency of our body, so to speak—but it is converted into such a form that it can be added to the blood to renew that fluid out of which our tissues are repaired and through whose agency fuel is supplied to the body for the purpose of supplying it with energy. In this paper it is my aim to give some account of the digestive process at large, laying special stress on certain curiosities of that process which appear to be singularly worthy our consideration.

One of the most interesting discoveries of recent times has been that which demonstrates that in plants as well as in animals a process of actual digestion takes place, whereby whatever food materials they consume are assimilated and applied to the purposes of their bodies. It has long been known, of course, that a veritable process of digestion, carried out through means strikingly resembling those found in animals, occurs in certain plants. To these cases I shall make allusion presently, but it appears probable that every plant exhibits a digestive process in the sense that it is supplied with certain ferments or bodies, the action of which upon their foods converts these nutriments into a shape in which they become available for the due nourishment of the plant. The more striking curiosities of digestion which plants exhibit might, however, be more distinctly illustrated by the case of the pitcher plants. These plants must be fairly well known to all readers who have visited botanical gardens. They are natives of the tropics, and possess leaves developed in the shape of pitchers. Each leaf possesses a long stalk, which expands into a pitcher, at the top of which we find a lid, this last probably representing the blade of the leaf itself. The pitcher leaves are for the most part highly coloured, and are extremely attractive. It was observed long ago by botanists that inside these pitchers fluid was contained, but this fluid was believed to represent either water itself or some watery solution. More exact understanding of the pitcher plant shows us that each of these curiously modified leaves is nothing more or less than a vegetable stomach. On the surface of the lid there are cells which secrete honey, whilst on the rim of the pitcher a similar sweet attraction for insects is found.*

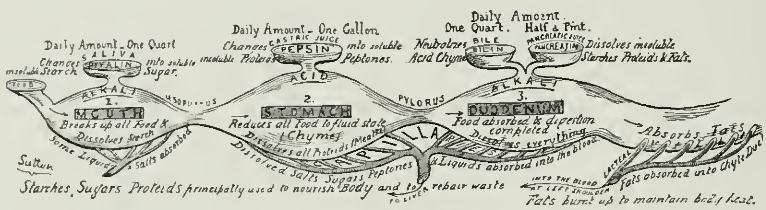


FIG. I.—THE DIGESTIVE PROCESS OUTLINED.

Digestion begins in the mouth under the action of the saliva, and change follows change as the food passes through the body in its long and devious journey.

As the insects die, their tissues are dissolved in the fluid contained within the pitcher. The inside of each of these curious cavities seems to be divided into three zones. The last zone is furnished with glands, which secrete a certain special digestive fluid. It so happens that closer examination of this fluid has revealed the interesting fact that it presents certain remarkable resemblances to certain digestive fluids of our own bodies. The digestive fluid of our stomach is termed

* *See* "Carnivorous Plants," CASSELL'S POPULAR SCIENCE, Vol. I., p. 357.

gastric juice, and it contains two chief constituents, known as *pepsin* and *hydrochloric acid.* Another digestive fluid of the animal body is that furnished by the

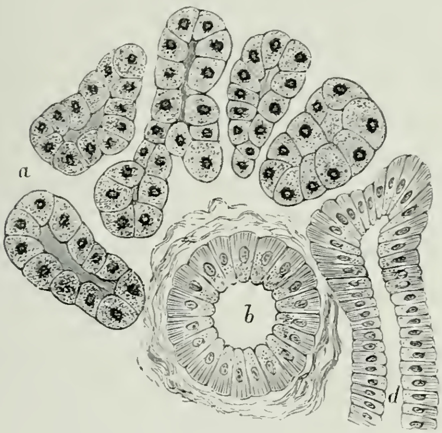


FIG. 2.—MICROSCOPIC SECTION OF A SALIVARY GLAND.

a, Clumps of cells; b, section through a duct; d, longitudinal section through a duct.

sweetbread and known as *pancreatic juice.* This is a complex fluid, containing several ferments—one of them, *trypsin*, performing much the same duty in digestion as the "gastric juice" of the stomach. It is interesting to note that recent researches carried out by Professor Vines seem to indicate that the secretion whereby plants are enabled to act in this way with animal matter more closely resembles the sweetbread juice than the gastric juice. Thus the whole process may be considered a veritable curiosity of digestion. The animal is largely maintained by the plant, but the plant returns the compliment in this case, and subsists on the animal.

Turning now to the consideration of digestion as represented more especially in our own frames, we find many points of deep interest. Any digestive system (Fig. 1), whether that of the worm or of man, may be described as a tube. In the lower animals this tube is of simple character, and is short and straight. In higher animals the tube exhibits a greater complexity, and increases in length. Digestion may be described as the progress of food along this tube. In the course of its journey food is subjected to various processes of a chemical and a physical nature, with the result that, when digestion is concluded, it is converted, as we have seen, into a form in which it can be absorbed and passed into the blood. There is, however, another item of importance in considering this general view of the digestive system. Attached to the sides of the digestive tube we find a number of organs, termed *digestive glands.* Each of these organs opens by a little tube or duct of its own into the digestive tube,

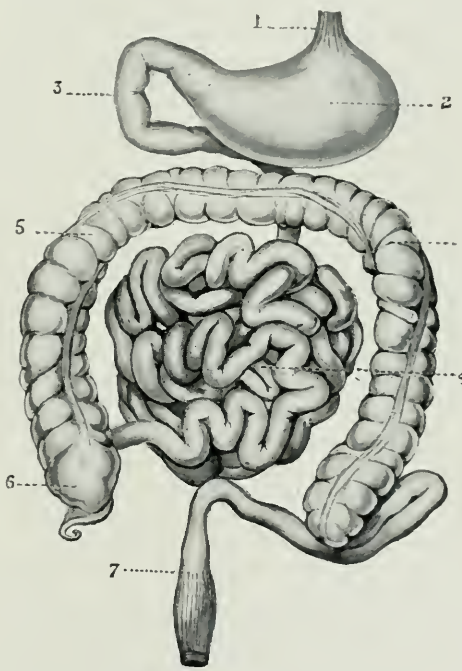


FIG. 3.—THE STOMACH AND INTESTINES.

(Man has 26 feet of intestine.)

1, æsophagus or gullet; 2, stomach; 3, duodenum; 4, coils of small intestine; 5, colon; 6, cæcum; 7, rectum.

and as each gland manufactures from the blood which is supplied to it a special fluid, we may readily conceive that such fluids poured on the food effect the changes necessary to fit it for the body's nourish-

ment. Examples of such glands are readily found. The salivary glands (Fig. 2), which supply the water of the mouth, may be said to represent the first of these digestive organs. In the stomach (Figs. 3, 4, and 5) we find glands of another kind embedded in the walls of the stomach (Fig. 8) and manufacturing the gastric juice, to which allusion has already been made. Passing beyond the stomach, we discover the liver (Figs. 4 and 6) and the sweetbread (Fig. 7). Each of these organs pours upon the food its own secretion after the food has left the stomach. The liver supplies "bile," whilst the sweetbread supplies "pancreatic juice." In the intestine, or bowel, we find other glands which also exercise a certain digestive action.

We have thus obtained a brief but correct view of the machinery of digestion. It may be said that this process begins in the mouth, for the water of the mouth, or saliva, has the power of converting the starch we eat (contained in bread, potatoes, rice, tapioca, etc.) into sugar. This faculty is also possessed by the sweetbread juice, so that, if the action of starch-conversion has been retarded or imperfectly performed in the mouth, such starch as is unchanged will be attacked and converted into sugar when it has left the stomach. The stomach itself presents certain interesting points for consideration. In the first place, it is an expanded part of the digestive tube, dilated for the reason that the food is detained within it for a certain period in order that it may undergo certain important changes. When food enters the stomach, the walls of the stomach contract, with the result that the food is kept in motion during the whole time of its stay there. The duration of the stay of a meal in the stomach varies, of course, according to the amount of food taken, and to the kind or quality of the nutriment, some food being much more readily digested than others.

A curiosity of digestion may certainly be found in the consideration of what the stomach really does with the food. A popular idea regarding digestion is that the stomach digests everything, and that it is the chief seat of the digestive work. This is an entirely erroneous idea, for the great bulk of the digestive work is not accomplished in the stomach at all, but in the intestine or bowel (Fig. 3), which in man measures twenty-six feet in length. To understand clearly the function played by the stomach in digestion, we must remember that

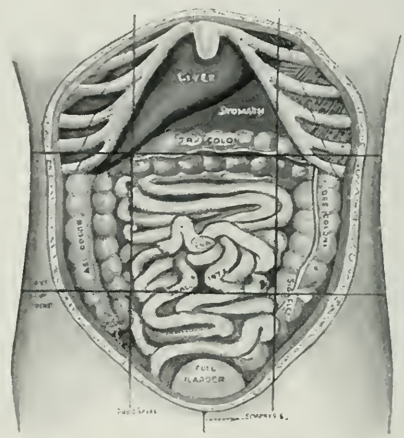


FIG. 4.—THE LIVER, STOMACH, AND INTESTINES.
Viewed from the front.

leaving out minerals and water (necessary parts of our nutriment), our ordinary articles of diet are divisible into two classes. These are respectively termed the *nitrogenous* and *non-nitrogenous* foods. The "nitrogenous" foods are represented by *meat albumen* and *egg albumen*, this last being the white of egg; by *casein*, or curd of milk; by *legumen*, by peas, beans, and lentils, and by other substances of allied chemical composition. The "non-nitrogenous" foods include fats, starches, and sugars. Now, upon the latter class of substances the stomach exerts practically little or no power. It is the nitrogenous foods with which the stomach's organs are specially concerned. Let us therefore try to understand what occurs

in the process of digestion in so far as the stomach's work is concerned.

The gastric juice is poured out upon the food in the stomach, and the movements of the stomach cause this juice to be freely mixed with the contents of the organ. The "pepsin" and acid contained in this juice seize upon the nitrogenous foods contained in the meal, and convert them into *peptones*. It is not necessary to indicate the somewhat complex chemical changes involved in this conversion. Suffice it to say that nitrogenous food converted into a "peptone" exhibits at least one quality it did not possess before it was swallowed. That quality is represented by the power it now possesses as a peptone of easily passing through the walls of the stomach and being absorbed by the blood-vessels. The blood-vessels of the stomach, in this case, receive these peptones and convey them in due course to the liver. This may seem to be altogether a somewhat curious story, and from it we may draw the following conclusions:—

(1) The stomach may be described as a kind of halfway-house on the digestive journey, where the food is detained for a time in order that all the nitrogenous matters may be removed and conveyed to the liver.

(2) The great bulk of every meal consisting of non-nitrogenous foods passes out of the stomach to be digested elsewhere—namely, in the intestines.

The work of the stomach apparently, therefore, from being of a very important character as regards its bulk, is seen to be in one sense comparatively trifling, yet it must be regarded as one of extreme importance, for we see that it provides what one might term a short cut into the blood, through the liver, for the nitrogenous foods. Nature appears to be teaching us that it is of importance that those foods which go to build up our body should quickly pass into the blood system. Why they should reach their destination through the liver is another story, constituting another curiosity of digestion, to which reference will presently be made. I have always compared the stomach to a custom-house situated on the frontier of a country where the baggage of travellers passing into that country is examined by the officials. The gastric juice might be compared to the custom-house officers. Fats, starches, and sugars allowed to pass out of the stomach would correspond to articles on which no duty was payable. The nitrogenous foods, on the other hand, might be likened to contraband goods, or to those on which a tax was payable, and the liver would represent the depôt to which they were carried, in order that they might there be taxed and dealt with.

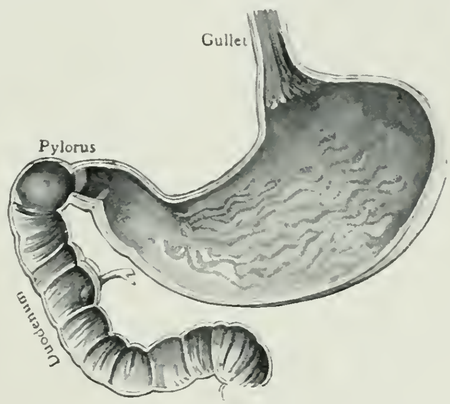


FIG. 5.—THE STOMACH: INTERIOR.
The stomach is the halfway-house on the digestive journey.

The story of the liver (Figs. 4 and 6) introduces us to another digestive curiosity. It is the largest gland in the body, weighing between three and four pounds, and situated under the lower ribs, to the right side of the body. Essentially, the liver is composed of untold thousands of microscopic cells, which average in diameter about the one-thousandth part of an inch. These cells are living bodies, and constitute what we might term the

workmen of this liver colony. The functions and duties of the liver are carried out by these cells. Entering the liver, we find a large vein called the *portal vein*, which returns blood from the whole digestive system, and it is into this vein that the blood-vessels of the stomach, carrying the peptones, pass. Now the question arises, What do the liver cells do with the peptones whose history we have already traced ? The answer to this inquiry may be summed up in the statement that they change them into a form suitable for passing out of the liver directly into the blood, where they become available for the body's wants. Why Nature should take this trouble of altering the peptones forms one of the most interesting features of the digestive process. If peptones were allowed to pass as such into the blood, they would produce effects akin to those of poisoning, and the curious feature is thus revealed to us that perfectly healthy food principles at a certain stage of digestion are really converted into substances hurtful and injurious to us. The liver's work is to rob them of these injurious properties

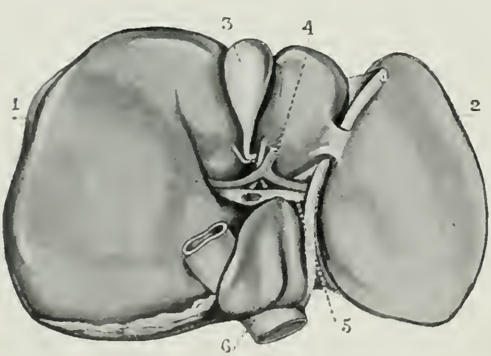


FIG. 6.—THE LIVER : INFERIOR SURFACE.
1, right lobe ; 2, left lobe ; 3, gall-bladder ; 4 and 5, ducts ; 6, portal vein.

and to fit them, as we have seen, for the body's nourishment.

It is highly probable that many liver ailments associated with biliousness, sickness, headache, and the like, are really caused by what may be called peptone poisoning. Thus it is the first duty of the liver to act as a kind of filter or screen between the nitrogenous foods on the one hand and the blood on the other.

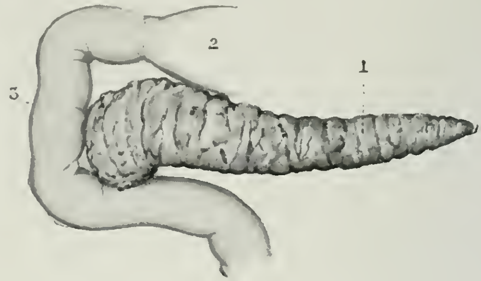


FIG. 7.—" PANCREAS " OR " SWEETBREAD."
While the liver produces bile, the sweetbread supplies " pancreatic juice."
1, sweetbread ; 2, end of stomach ; 3, beginning of intestine.

The story of the liver is, however, hardly exhausted with this account of its labours. Another and extremely interesting part of its duty is that involved in dealing with the starchy elements of our food. We have seen that starch is converted by the saliva of the mouth into a sugar, and also that the sweetbread juice has a power of producing a similar result. Now this sugar is absorbed from the digestive system, and ultimately finds its way into the " portal vein," and thence passes into the liver. The liver cells appear to reconvert this sugar into a starch, which is known as *glycogen*, or animal starch. In this latter form the sugar is stored up in the liver cells. In 1848 the great French physiologist, Claude Bernard, made a most important contribution to our knowledge of the work of the liver when he showed that part of its work consisted in again turning this stored-up starch in its cells into sugar, and in that form paying it out to the blood. Conveyed by the vital fluid to all parts of the body, and especially to the muscles, the sugar thus became utilised as a food. On this view the liver might be regarded as a storehouse for starch.

We may say that the fate of all the starch we take is to end its existence as

sugar, for in this shape alone—sugar—being much more soluble than starch, can it be utilised by the tissues of the body. These views of sugar production by the liver from its stored-up starch have been questioned. Some authorities hold that the fate of the sugar is not that of being paid out to the blood, but rather that of its conversion into fat and into other bodies. There can be little doubt that the liver has a power of forming fat from sugar, and it is just possible that this organ may discharge both duties. The balance of evidence is undoubtedly in favour of the fact that the liver does pay out sugar in the manner described to the blood. It may be interesting here to note that when this sugar is paid out either in too great quantity (or it may be when the body, from one cause and another, is not capable of utilising it), the disease called *diabetes* is produced—a disease attended by great wasting of the body and by other symptoms connected with the great stress of work thrown in that case upon the kidneys.

The duty of the sweetbread (Fig. 7) appears to be that of acting upon practically all kinds of food. Indeed, it is the only organ in the body which has a power to digest nitrogenous and non-nitrogenous substances. It certainly can act in the same way as the gastric juice of the stomach. It can also convert starch into sugar. It has a certain action on fats—although the bile of the liver has much more to do with their digestion than the sweetbread juice itself—and, finally, it possesses a power of curdling milk.

We are now in a position to see what, at the close of digestion, remains of our food to be absorbed into the blood. The nitrogenous foods have already passed into the blood through the liver. The starches have been taken up into the liver, and there dealt with as described. What remains in the intestine after the bile and sweetbread juice have acted upon the food will therefore be largely fatty materials. It is these materials which are taken up to the blood by vessels called *absorbents*, which end in a tube running up the left side of the spine, and called the *thoracic duct* (Fig. 9). This duct opens into a large vein at the root of the neck on the left side (*b*). This point therefore marks the junction of our food with the blood, or at least so much of the food as is directly passed outwards from the intestine into the blood.

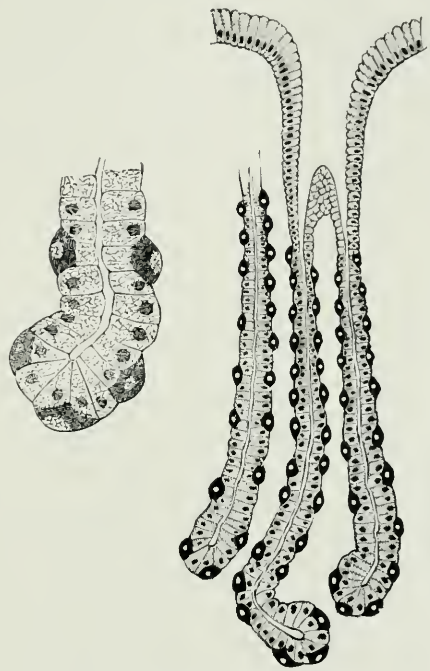


FIG. 8.—GLANDS OF THE STOMACH, OR PEPTIC GLANDS.

A final curiosity of digestion, but one to which the briefest reference only is permissible, is that connected with the part played in the process by bacteria or microbes. It is, of course, well known that the great world of microbes includes many which are harmless, some which are useful, and others which are injurious to us. Amongst the useful bacteria are those which are connected with the digestive process. We have yet to learn a good deal connected with the exact part which germs

may be said to play in the digestive process, but it is tolerably certain that microbes aid the work of many of the ferments to which I have shown the chemical changes incidental to digestion are due. Particularly in the intestine or bowel bacteria are found, and although many of these are not directly connected with the digestive process, others seem to play a definite part in it. It is certain that many of them aid in preventing decomposition or putrefaction of the food in the intestine. Some authorities incline to the belief that the part played by microbes is of much more importance than that which would limit their action to the work in the intestine. As one author has well said, "It would appear in fact as though there were developed special organisms for the setting up of special fermentations, and also that after the breaking down has been carried a certain length by one organism, the aid of another is invoked to complete the process more thoroughly and expeditiously." This remark is probably true of the work of germs in digestion, and not the least curious feature of such a subject as this is the part which the humblest of organisms may play in assisting the highest.

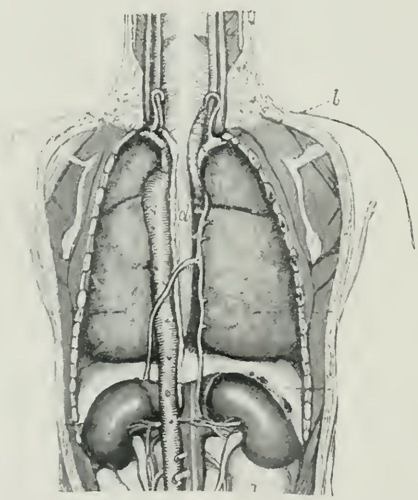


FIG. 9.—VIEW OF THE THORACIC DUCT (*d*) AND ABSORBENTS.
The point of union with the blood is marked b.

A FEATHER.

IT requires no scientific experience, and only the most superficial observation, to know that birds' feathers vary infinitely in shape and hue. We have the gaudy plumes of the peacock, and the more sombre garb of his mate ; the black covering of the raven, and the snowy plumage of the ivory gull. But when feathers are examined from the anatomist's point of view, the bright hues which give them character, and even the endless forms of the bird's covering, become altogether secondary, and, as it were, trivial matters of detail. The study of the development of feathers shows that they are identical in origin, and that, however much they may differ in their adult state, they have certain broad invariable features in common. First, then, let us examine the anatomy of a feather.

The hard substance of the feather—that is to say, the part which resists alike wet and putrefaction—belongs to the same category of horny productions of the animal body as hairs and finger-nails.

We can separate a full-grown feather—such as that of a fowl's back—into three different parts (Figs. 1 and 2).

First there is the stem, or *scapus* ; it is the strongest part of the feather, and consists of two parts. The base from which pens are made is the quill (*calamus*), and is hollow, round, transparent, and colourless ; whilst the upper and far longer part, the shaft (*rachis*), is more or less quadrangularly compressed, and filled inside with a pithy substance, very similar in appearance to the white and light interior of an elder twig. This shaft supports the vane (*vexillum*), which is made up, in the first place, of barbs (*rami*), and forms the second important part of the feather. The barbs, although small, number several thousands in a large feather. They lie with their flat sides one on the top of the other, and are so placed that one edge looks upwards and outwards, while the other looks downwards and towards the body of the bird.

In the next place, there are the barbules (*radii*) (Figs. 3 and 4), which have the same relation to the barbs as the latter have to the shaft, so that each barb with its barbules is a miniature feather in itself. The manner of their arrangement is, however, different—the barbules attached to the upper edge of the barbs point in the direction of the tip of the feather, while those issuing from the under edge are directed backwards and outwards. The number of barbules on the barb is very large, as can be seen with the naked

FIG. 1.—QUILL FEATHER OF A CRANE, SHOWING "STEM," "SHAFT," AND "VANE."

eye. They are the tiny things seen between the branches of the web when we hold the latter up against the light, and carefully try to detach them from one another. In attempting to do this, however, we at once remark that we cannot so easily separate the barbs, but that they cling to each other as if they were glued together. This is the result of the peculiar structure of the barbules, which, as we shall soon see, are of very different shapes.

FIG. 2.—PHEASANT'S FEATHER, SHOWING THE "SHAFT," "VANE," AND "AFTER-SHAFT."

In most cases there issue from the outer side of those barbules which are directed towards the edge of the whole feather, additional very thin, thread-like lashes, which we can see only under a strong power of the microscope. These are the barbicels (*cilia*). Their greatest development takes place, on the average, in the middle part of the barbules, where some of them are bent at their tips like hooklets. These hooklets are of very great importance—in spite of their surprising smallness—because their tiny tips, clasping round the somewhat thickened edge of the next barbule, fasten on to the latter, and thus hold all the barbules together. By this arrangement a double advantage is effected. Firstly, the neighbouring barbules, and through these also the barbs, are bound, or combined together, to form a flat and broad plane—the so-called "web"—by means of which the bird can cause a pressure on the air, and is enabled to rise above ground, and to fly; secondly, the whole web is now elastic, to a very great extent, as by the motion and bending of the web all the innumerable single hooklets slide up and down on the edges of the barbules as in a hinge, so that to loosen them becomes almost impossible.

FIG. 3.—BARBULE OF HAWK'S DOWN. (*Magnified.*)

The barbicels themselves exhibit, in the several kinds of feathers and in the different families of birds, very great variations in shape, as well as in their number. The total number of the barbicels and hooklets on every barbule amounts, on an average, to half-a-dozen. Again, in several places, and in different kinds of feathers, even on one and the same bird, the barbicels consist simply of

FIG. 4.—BARBULES FROM A PIGEON'S QUILL. (*Magnified.*)
a, ordinary; b, from near the tip.

quite short points—as, for instance, near the tip of a feather from a duck's back. Others, again, have the shape of very small irregular cups, or, especially on the tips of the downy feathers, they are represented merely by small knots. Accordingly, some authors make a distinction between simple, knotted, and branched barbules.

FIG. 5. — PIGEON'S FEATHER WITH NO AFTER-SHAFT.

Another part in many feathers is the so-called *after-shaft*, or *hypo-rachis* (Figs. 2, 6, and 16). As it consists of a shaft which sends forth again smaller branches in two opposite directions, it seems like a separate feather. The whole "after-shaft" springs from the inner side of an ordinary feather at the place where the quill meets the pith-containing and web-carrying shaft, just where the so-called "*soul*" of the feather sticks out (this region of the feather being known as its "nabel"). Such an after-shaft shows its greatest development in some of the ostrich-like birds; in the covering feathers of the Cassowary, Dromaius, and Apteryx it is of the same length, and of exactly the same structure, as the real feathers, so that every one taken from the back of such a bird seems to be double.

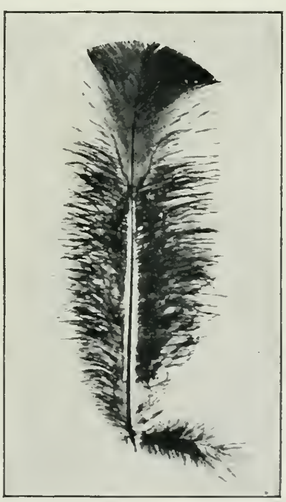


FIG. 6. — TURKEY'S FEATHER WITH A SMALL AFTER-SHAFT.

In most of the other birds the after-shaft is very small—as, for instance, in domestic fowls, ducks, geese, waders, and singing birds. Many other birds—as, for instance, the owls, cuckoos, pigeons (Fig. 5), and cormorants—entirely want the after-shaft. It is, moreover, never found on the great quills of the wing and tail. Let us now, for curiosity's sake, count up and see how

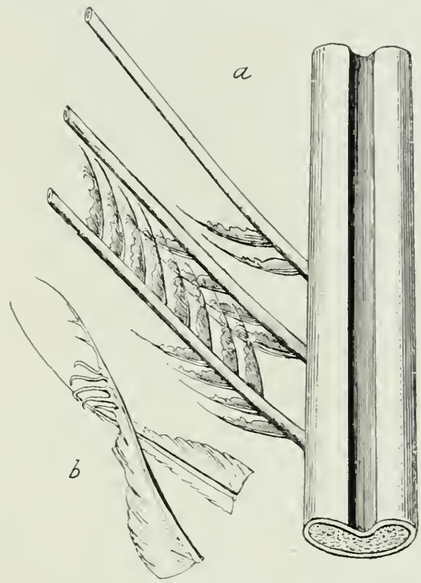


FIG. 7.—*a*, UNDER-VIEW OF A PART OF THE SHAFT OF A QUILL FEATHER; *b*, TWO BARBULES ENLARGED.

many of the parts mentioned above go to make up a single feather. We take for example an eagle's quill, the web of which is fifteen inches in length.

On the inner web we find about eleven hundred barbs; on the outer web about nine hundred. From each side of one of the longest barbs of the former issue about fifteen hundred pairs of barbules; consequently, on it alone there are at least six thousand of these. The barbs at the different parts of the web being of a different length, we will take as the average number of the barbules on each as being about 2,000 pairs, or 4,000 single ones.

On every barb of the outer web there are about 600 pairs or 1,200 single barbules. Every one of the latter, again, sends out

about ten barbicels and hooklets on the outer web, as well as in the inner one, with this result :—

Inner web has 1,100 barbs, each with 4,000 barbules, making 4,400,000 in all.

Outer web has 900 barbs with 1,200 barbules, making 1,080,000.

The whole web of 2,000 barbs has thus 5,480,000 barbules, which, with the barbicels and hooklets, gives a total of about 60,000,000 parts.

So this single feather contains about two thousand barbs, five million and a half of barbules, and the surprising number of more than fifty-four millions of barbicels and hooklets! Roughly speaking, therefore, it consists of sixty millions of parts. How large, then, will be the number of these things in one of the long and beautiful feathers of a bird like a peacock may be imagined, for, in fact, they exist in numbers almost impossible for us to estimate.

A bird is born unfeathered. The feathers grow after it emerges from the shell ; for the fluffy down with which the skin of the young chick is clothed is but the promise of the covering of its maturity.

How, then, is developed such a complicated and delicate structure as a feather, which contains, at the same time, so much strength and elasticity ? This leads us to inquire into and follow its growth from the earliest stages to the perfect form.

The commencement of the growth of a feather is surprisingly simple. Let us take for examination the egg of a young fowl, or a duck, after it has been sat upon by the mother long enough for the embryo, or young animal, to be developed by her animal heat from the substance of the egg. Let us look, at the end of the first week, at the still quite soft skin of the embryo. In birds, as in mammals, the skin consists of two principal layers ; first, a very thin horny layer, which surrounds the whole of the bird externally—this is known as the *epidermis* ; secondly, a thicker, softer, and more tenacious under-layer, immediately covering the muscles of the body—this is called the *dermis*, or leathery skin. The latter is very juicy, and full of blood, and forms the substance which, when tanned, we ordinarily know as leather. The part of the epidermis next to the dermis is known as the *stratum Malpighii*, which forms the cuticle, and renews the latter when it is worn off by daily friction. Such a wearing off of the epidermal layer is seen in the scurf which falls from our heads in daily life. The *stratum Malpighii* itself consists of a layer of small cells, visible only under the microscope.

To return, however, to our chick. Its whole skin begins to show in many places small irregularities of surface or elevations which, gradually becoming bigger and higher, form small pimples (*papillæ*). The whole thing is caused by a swelling of the dermis and the *stratum Malpighii*. Very soon, however, the base of this small lump sinks deeper, carrying with it the surrounding epidermis, and so causes a growth to form, from the middle of which projects the first beginning of the future feather, the so-called *pulpa pennæ*—or "feather pulp."

When examined under the microscope, a longitudinal section of the whole organ would appear as shown in Fig. 8. The whole is the papilla, with the pouch-like depression, and all is covered by the epidermis (*e*), underneath which is the layer of cells of the *stratum Malpighii* (*M*), and below that the true dermis covering the muscles (*f*). In this dermis are seen an artery (*A*) and a vein (*V*), which are the blood-vessels which supply the future feather with blood—*i.e.* the means of nourishment. The elevation (*P*) is the pulpa, the real germ of the feather.

This pulpa now begins to change its simple form. The basal portion (that nearest the flesh of the bird) becomes, as it were, strangled, and gets an onion-like shape (P_2 in Fig. 9), whilst the upper part (P_1) increases in length, and stretches upward more and more. The surrounding cells (*M*) of the *stratum Malpighii* multiply,

and grow also in length, by dividing themselves longitudinally and transversely, and then getting hard and horny, like our finger-nails. Then every one of these series of cells grows to a fine horny thread, which begets, moreover, on the sides, smaller threads, only visible with a lens, perforating the epidermis. We now see sticking out of the top of the "pimple" a little tuft of about a dozen bristles, like a small paint-brush. The outer layer (the epidermis) is torn by this process, and falls off in small scurfy pieces at the time when the young chicken comes out of the egg.

A longitudinal section of such a young primitive feather exhibits the following aspect (Fig. 9):—

F is the small feather-brush; *e*, the falling-off scurf of the epidermis; *M*, the two layers of the mucous layer, or *stratum Malpighii*, like the finger of a glove drawn back half-way into the glove; P_1, the upper part, and P_2, the basal part, of the pulpa, in which the artery and the veins are seen.

Now, such feather-brushes being distributed over nearly the whole surface of the body, the young bird, when it emerges from the egg, has got a soft covering, which serves as its first protection against the cold and wet. However, such a simple covering is not sufficient for very long, since the young bird, as it increases in size, cannot any longer be covered and warmed by its parents; besides this, it will have to fly, and for this purpose it wants large and strong feathers.

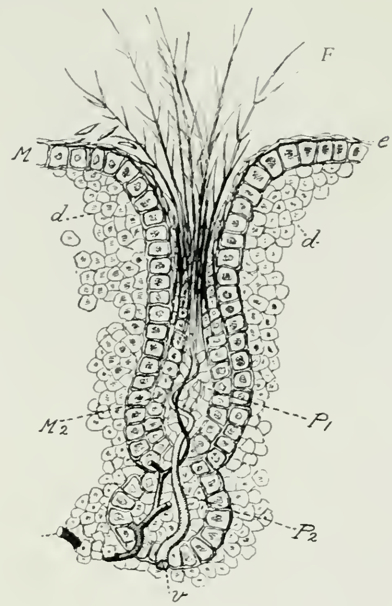


FIG. 9.—THE DOWN GROWS WHILE YET THE BIRD IS IN THE SHELL.

References as in Fig. 8: F, feather brush: P_1, P_2, pulp of feather.

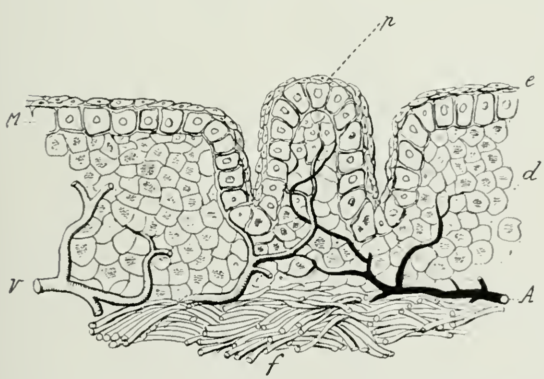


FIG. 8.—HOW A FEATHER GROWS: LONGITUDINAL SECTION OF THE SKIN, SHOWING "PAPILLÆ."

A, artery; d, dermis; e, epidermis; f, muscles; p, young feather; M, "stratum Malpighii"; v, vein.

The small, tiny feathers, therefore, the growth of which we have examined already, fall out after they have fulfilled their purpose, the artery ceasing to carry any more blood into the upper part of the pulpa, and so consequently the feather-brush dries up and dies.

The basal, onion-like half of the pulpa, which had become separated from the first foundation (seen in Fig. 9, P_2), begins to grow, and becomes so long that it sticks out to a considerable distance from the body, and pushes the first downy feather-brush off (Fig. 11). At the same time the surrounding cells of the mucous layer grow and multiply in number very quickly. At first branches develop from the uppermost cells quite similar to those which we have seen in the first covering of the nestling. These branches stick out of the

skin, and form the top of the new definitive feather. The outermost cells of the mucous layer transform themselves into a

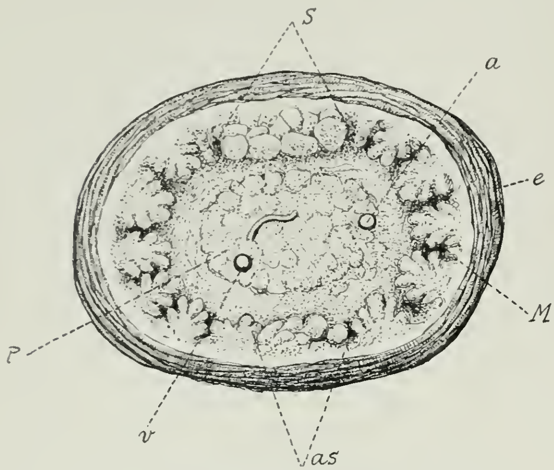


FIG. 10.—TRANSVERSE SECTION OF A GROWING FEATHER THROUGH THE POINT MARKED *S* IN FIG. 11.

a, artery; v, vein; e, epidermis; M, stratum Malpighii; P. pulpa; S. cells which form the shaft; a s, cells which form the after-shaft.

horny, thin, and transparent sheath for the young feather. Later on, the feather having grown larger, this sheath bursts, and falls off in pieces. At this stage the bird is now in the condition known to everyone as "pen-feathered," and when it shakes itself the scurfy scales fall off in every direction. Then the pulpa grows more and more in length, and forms that part which, full of blood and nourishing juice, and of a reddish-blue colour, is the basal half of the not yet fully-grown feather. A transverse section of this part would give us the appearance shown in Fig. 10.

At first one of the marginal cells increases considerably in bulk at the expense of its neighbours, and occupies the greater part of one side; it ultimately transforms itself into the strong shaft of the feather, giving a base for the barbs with their component barbules. These barbs originate from the remaining marginal cells of the *stratum Malpighii* (*M*), and form, as we have shown above, the web of the feather. When the web has grown to its full length, the marginal cells cease to produce barbs, and amalgamate into a strong horny ring (as it appears in transverse section). It is this part which is called the "quill" of the feather.

Everywhere, when the shaft with its barbs is perfected, the function of the pulpa ceases, the juice is used up, the vessels inside dry at its summit, and at the same time it naturally gets shorter, and retires upon itself towards the base of the feather. Only the outer shell of the pulpa remains, and as it retires little by little at certain intervals, a succession of small transparent air-containing caps is formed inside the quill, known as the "soul." This "soul" is familiar to everybody who has cut a quill, as it has to be withdrawn before the pen will write (Fig. 12).

Finally, when the feather has reached its full size, it is attached to the skin by only a very small portion of it, the pulpa

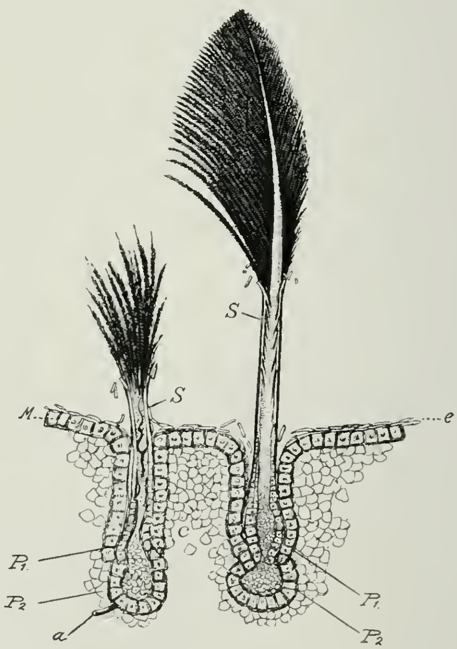


FIG. 11.—SHOWING THE RELATION OF GROWING FEATHERS TO EACH OTHER.

References as in Fig. 9.

having contracted to its original onion-shaped bulb. The feather is now perfect.

The beautiful and often surprisingly magnificent colouring of the plumage is

commonly derived from pigment, which is collected in the *stratum Malpighii*, and is probably also generated therein.

We see the same arrangement in the colour of the different races of mankind. The black colour of the negroes, the Papuans, and the aborigines of Australia, the coppery-red of the American Indians, the yellow of the Mongols, and the brown of the Malays, is produced by black, red, yellow, or brown pigment cells, existing in the mucous layer of the *stratum Malpighii*, and shining through the transparent epidermis. In Europeans this layer contains no pigment whatever, but the blood and flesh shine through the upper skin, and produce the rosy whitish tinge characteristic of their skin.

Sometimes, however, structural peculiarities give rise to "interference" colours, as in the case of the metallic appearance of the peacock's "eye" feathers. Pigment, however, plays an important part in enhancing the effects.

When the feathers are abraded or worn with use, or when the bird gets its winter coat or its breeding dress in the spring, a necessity for developing new feathers arises. Then the small pulpa (P_2, Fig. 9) revives, new juices being supplied to it by the artery, and, increasing once more in length, again goes through the process we have described above, and pushes out the old feather exactly as in its infant stage it got rid of the original downy plume. This process being carried out in many feathers at the same time, the bird "moults." Again, when a feather is torn out of a bird at any other time than the moulting season, the pulpa is always ready to supply a new one. Thus it happens that when one of our pet birds loses a feather, or even if one pulls out its whole tail by accident, we have the comfort of knowing that in a few weeks it will develop fresh and, perhaps, even more beautiful plumage.

According to their structure and the different parts of the body on which they are found, we may distinguish several kinds of feathers, which, while not strictly different from each other, often show, even

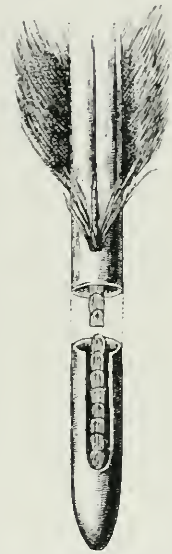


FIG. 12.—EVEN A FEATHER HAS A "SOUL."

The "soul" is the outer dried shell of the once active "pulpa"; it is found inside the quill.

in one and the same bird, all kinds of intermediate forms.

Firstly, there are the downy feathers (*plumulæ*). These are rather short, fine, and generally white, with a weak shaft, but have comparatively long and very thin barbs and a few barbules, though they generally want the barbicels and hooklets. These plumes, known as down, are situated in the fully grown bird between the "contour" feathers. They are entirely covered by the latter, and are thus not visible from the outer surface of the body. Their exclusive use is to provide the bird with a warm covering; they are, therefore, most developed in the swimming birds, especially in those which live in cold climates. To us they are of great use, as we use them for filling our coverlets and pillows, those considered the best and most in demand being the "down" of the Eider duck (*Somateria mollissima*).

The first covering of the nestlings is also composed of down-like feathers, and not before the lapse of a considerable time do the young birds get true feathers, like those of the parents. These nestling plumes are of great scientific interest, as very possibly they indicate the remnants of a former state of primitive feathering, showing that the birds of former periods were covered simply with feathers more like those which are now seen merely in the first plumage of the young ones.

Naturalists have acknowledged, as a law of universal value, that the young of animals, especially when they are in an undeveloped state, differ in many points from their parents, and that these differences point to a state of lower organisation, resembling that of their ancient progenitors. Thus by the appearance of the young animals we are led to suspect their probable relationship. Accordingly, many naturalists have used the feathering of birds and the different conditions of the nestlings at their birth as means of classification, and have divided them into two great orders, called *Ptilopædes** and *Psilopædes*.† Thus the chickens of the first order, the *Ptilopædes*, when hatched, are covered with down all over their body, and are able to supply themselves with food from the moment of their exclusion from the egg; whereas the second order, the *Psilopædes*, are hatched without any down upon them, and are brought into the world naked, helpless, and blind, depending on the care of their parents for a supply of food and warmth, until they become strong enough to shift for themselves. Familiar examples of psilopædic nestlings are to be seen in the sparrow, canary, and thrush, while the chicks of the domestic fowl or duck, of a coot or a moorhen, are illustrations of the ptilopædic birds. A young coot or moorhen, which, when hatched, looks like a tiny ball of black down, will, on the approach of danger, take to the water at once, and I have more than once found the nest with eggs partially hatched, with the bills of the little ones peeping through the shells, but none of the other nestlings in the nest itself: they had all swum away, or hidden themselves among the reeds.

This kind of classification, however, has not met with universal approval by zoologists; for though the differences of these two groups of birds are very great, the birds of our own area exhibit too many exceptions to the rule. Thus, for instance, although the birds of prey, when hatched, are covered with a rather thick downy covering, they are helpless and blind at birth, and cannot leave their nests. Once more, the young gulls are hatched with a thick downy covering, but sit for a long time in their rudely formed nest before they make an attempt to take to the sea.

A very remarkable exception to the state of development in which certain birds leave the egg is seen in the talegallas and the megapodes. The latter, to which the mound-building *Megapodius Freycineti* belongs, live in Australia and the Moluccas, and, as the eggs are very large, the hen does not sit at all, but buries them in the black sand by the shore. The sand is warmed by the hot tropical sun, and loses but little of its heat by night, being almost the same as the blood of the bird, viz. about 104° Fahr. The young megapodes, however, leave the egg neither in down nor yet naked, but with feathers over their body, and wings sufficiently developed for flight.

Still more wonderful is the talegalla bird, found in New South Wales. The pair in the Berlin Zoological Gardens have been a never-failing source of interest. On one occasion it was observed that the male in the breeding period collected with its feet all the available moss, withered and rotten leaves, small branches, and earth, and built with them an immense heap. This heap he con-

* From the Greek words *ptilon*, a downy feather, and *pais*, a child or young one.

† From *psilos*, naked, and *pais*.

tinually increased, until it reached a height of six feet, with a diameter of not less than ten. He then made deep holes in different parts of this mound, in which the hen deposited her eggs. For many weeks nothing more was noticed than that the cock occasionally inspected the heap, when he must undoubtedly have turned the eggs. The heap itself showed a rather high temperature from the fermentation of the rotten leaves and other fermenting substances. This peculiar attempt had been given up by the officers of the gardens as hopeless, as they supposed that the climate was not fit for such kind of hatching, when one morning the keeper observed a young fowl crawling out of the heap, and saw to his great astonishment that this chick immediately flew over the neighbouring fence. Then there arose a hot chase in the "Thiergarten" by the alarmed keepers after that wonderful bird, until they got hold of the megapode chick. During the next days several other chickens were found, one of them having been unable or not strong enough to pierce the heap; and so it had been suffocated.

One might suppose that these birds have never had any down covering at all, since they leave the egg fully feathered. But more recent inquiries have shown that the young megapodes, as well as the talegallas, were covered with down before being hatched. This covering is much the same as in the ordinary domestic chicken, but gives place to the new feathers, which become developed and push the down off before the bird leaves the egg, and thus the first moulting takes place within the shell.

This is again a very remarkable example of the way in which the young of animals repeat in succession all the different stages of development through which their progenitors have gone; for without this presumption of inherited peculiarities the downy state within the egg would be as inexplicable as it is useless.

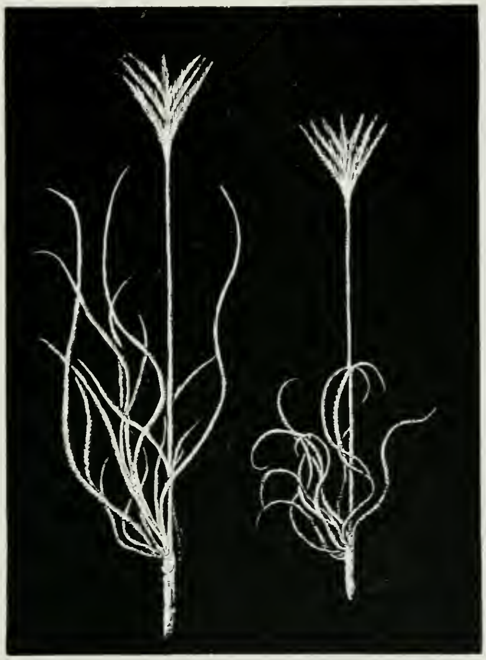


FIG. 13.—FILOPLUMES OF THE PIGEON.

We have now to treat the most important of all feathers, the so-called "contour feathers"— those, in fact, which are ordinarily known as "feathers." They are distinguished by a strong quill and a long shaft, armed with a double web emanating from its opposite sides; the down, on the other hand, has branches projecting equally all round, like the branches of a small fir tree.

The "contour feathers" are so called because they are on the outside, and give the visible shape or "contour" to the bird. These are the feathers exposed to the light. They often possess brilliant and varied colours, and are therefore of the greatest importance in determining the species of birds. "Contour feathers" are of several kinds. First, there are the ordinary clothing feathers. They are generally short, but comparatively broad

and more downy near the quill; they form the covering of the head, neck, breast, back, and the under part of the body. It is generally only the tips that are coloured, whilst the other parts are grey, whitish, or indistinctly marked.

The second kind of contour feathers are those which serve for flying, and are generally long and stiff—the so-called "quill feathers." Those which are situated on the wing are called *remiges*, whilst those of the tail are the *rectrices*, because they help to *direct* the flight of the bird through the air; as the tail, which generally consists of from ten to eighteen feathers, can be closed or spread out like a fan, and turned either to the right or left like a rudder. In good fliers—as, for example, birds of prey, pigeons, and swallows—the tail is very long and well developed. In bad fliers, on the contrary—waders and swimmers, for instance—the tail is short.

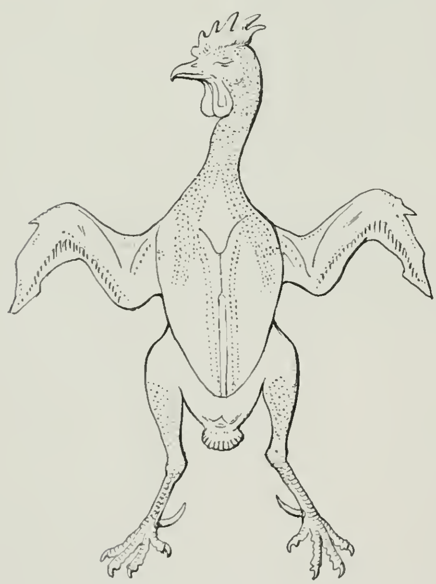


FIG. 14.—FEATHER TRACTS ON THE BREAST OF A COCK.
(After Nitzsch.)

Finally, in the ostrich, which does not fly at all, it is quite neglected, or developed for mere ornament.

Intermediate between these two kinds of feathers—those for covering and flying—there is a number of others, all of which have special names; but to describe them would lead us too far. In addition to the

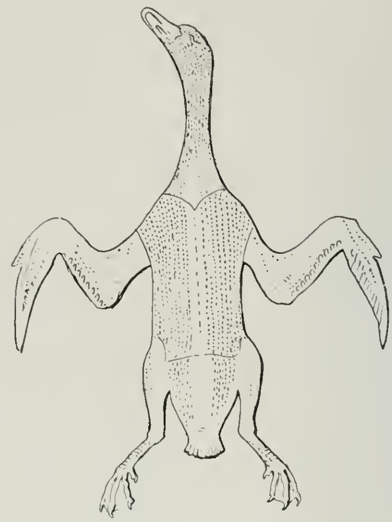


FIG 15.—FEATHER TRACTS ON THE UNDER SURFACE OF A DUCK.
(After Nitzsch.)

magnificently coloured feathers of some birds, as the peacock, we need only mention the most striking variations of the "covering feathers." To these belong the almost entirely ornamental and remarkably pretty and long feathers on the back of the head of the male heron and the crown-pigeon. The beautiful feathers of the bird of paradise, too often carried on ladies' hats, are not the quills of the wing, but highly developed and transformed feathers of the breast. So, also, those which compose the "bow" of the peacock are not tail feathers, but its extraordinarily developed covering feathers. The wing feathers of the African ostrich have lost their character as "remiges" (rowing feathers), and have become the well-known waving plumes, whilst those of the wings of the penguins, which only dive and swim, have turned quite small and scaly. The remarkable bare, stiff, and round points in the cassowary's wings are feathers whose whole development is confined to the quill—the web part being entirely absent. In this manner, also, the

eyelashes and the bristles on the bills of numerous birds are explicable ; they still show, but only at their base, the remains of a former web, and the presence of this web proves that they are to be considered as feathers, and not hair, as was formerly supposed.

We have now only to describe the distribution of feathers over the body of the bird. In only a few birds—as, *e.g.*, in the cassowary and the penguin — are the feathers equally distributed over the whole body, leaving no bare spots whatever, except the bill and feet. In almost all other birds it is found, on examining the body when plucked, that many parts are entirely destitute of feather pores, these places being covered by the overlapping of the feathers of the neighbouring parts of the body.

The proportion of these naked parts, called *apteria*, to the feathered ones (*pterylæ*) is important for the systematic classification of birds, as has been pointed out by Dr. Nitzsch, the discoverer of this arrangement. According to the different parts of the body where the "feather tracts" (Figs. 14 and 15) are found, they have different names—as, for instance, the neck, shoulder, and belly tracts. It will be easy for my readers to verify these remarks by reference to the birds already dealt with.

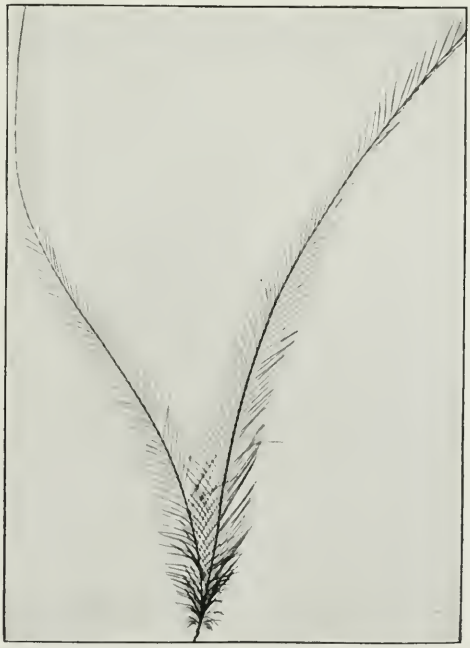


FIG. 16.—CASSOWARY'S FEATHER.
Here the shaft and after-shaft are approximately of the same length.

FIG. I.—SHETLAND PONIES, WITH FOALS.

THE HORSE AND ITS ANCESTORS.

By JOHN O. PEET, B.Sc.

(Lecturer in Agriculture at University College, Reading.)

BIOLOGISTS are able, from the materials at their disposal—chiefly the remains and impressions left in various parts of the earth's crust by the living things of past ages—to place before us some account of the life which existed on the earth during the various geological periods, in much the same way as an antiquary is able to reproduce from the ruins of an ancient building somewhat of its form and proportions for our imagination. The oldest rocks containing animal remains yield only those of simple forms, while, as we pass from these deposits to those of most recent formation, the fossil remains gradually change, and exhibit a more complex and specialised structure. Evidence points to these higher forms having descended from the lower ones. In course of time animals underwent great changes in form and structure; new organs or parts were acquired, and old ones lost. Sometimes the variations from the common types formed starting-points, as it were, for new families, which, developing along distinct lines, diverged more and more from the parent stock as time passed. The evolution of animals in this manner explains the general similarity in the structure of different groups, and the constant occurrence of organs which are now apparently useless, as well as various peculiarities in habits and instincts.

If we are to understand the evidence adduced regarding the genealogy of the horse, it is essential that we should first understand the position assigned to the animal in the system of classification adopted by zoologists. This we will briefly describe. It is evident that the animal is a *vertebrate* (*i.e.* it has a backbone) and a *mammal* (an animal whose female yields milk), and, further, it is not difficult to understand that it belongs to the great order *Ungulata* (hoofed animals).

one of the principal characters of which is that the extremities of the toes are more or less enclosed in the enlarged and thickened nails, the hoofs. There are two main sections or sub-orders of the order examples of this group. In the odd-toed section the third or middle toe is larger than any of the others; the second and fourth toes are in some cases well developed, sufficiently so to be of use to

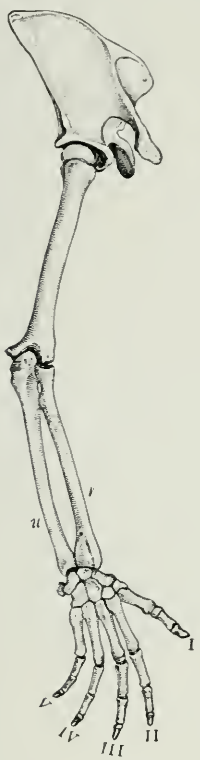


FIG. 2.—BONES OF THE HUMAN HAND AND ARM.

I, II, III, IV, V, the digits; r, radius; u, ulna.

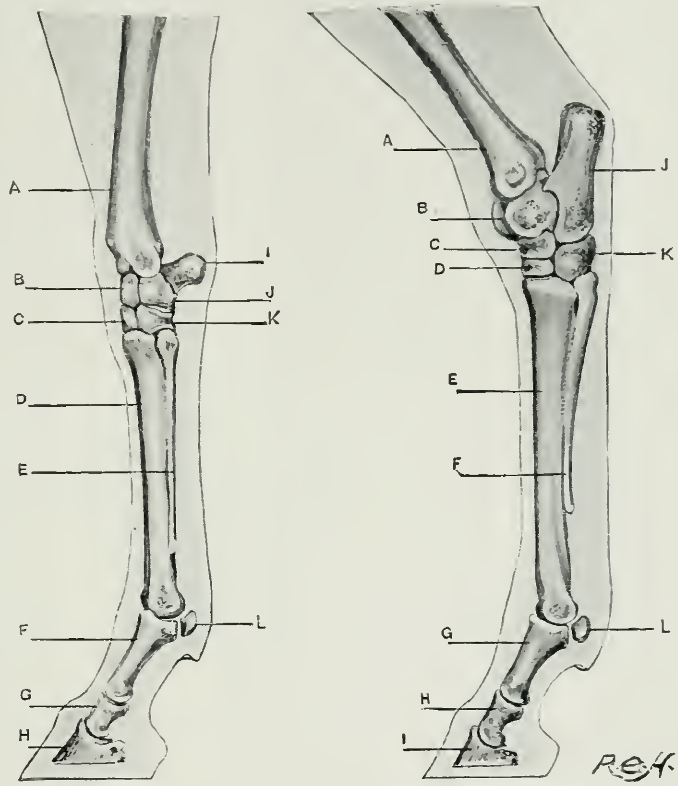


FIG. 3.—BONES OF THE HORSE'S FORE-LEG (*1*); HIND-LEG (*2*).

1. A, radius; B, lunare; C, magnum; D and E, metacarpals; F, pastern; G, coronet; H, pedal bones; I, pesiform; J, cuneiform; K, unciform; L, sesamoid.
2. A, tibia; B, astragalus; C, naviculare; D, cuneiform; E and F, metatarsals; J, calcaneum. Other references as in 1.

Ungulata—the *Artiodactyla* or "even-toed," and the *Perissodactyla* or "odd-toed." In mammals the number of toes never exceeds five, which are numbered, starting from the inner side of the limb—the thumb or great-toe side—1, 2, 3, 4, 5. In the even-toed section of "ungulates" the third and fourth toes are equally developed, and the line halving the foot runs between them. The second and fifth toes may also be present in a greater or less stage of development, but the first is never present. The ox, sheep, goat, pig, and deer are familiar the animal in walking or in other methods of progression. To this group belong the tapirs, the rhinoceroses, and the horses. The horse and its closely allied forms, the asses and the zebras, are grouped together as the genus *Equus*. These differ from all others in the structure of the limbs, particularly their terminations; and these organs have undergone marvellous changes in the course of evolution, greater, perhaps, than any other part of the body. This can be best described by comparing the bones with the corresponding ones in man.

The knee and hock of the horse correspond anatomically to the human wrist

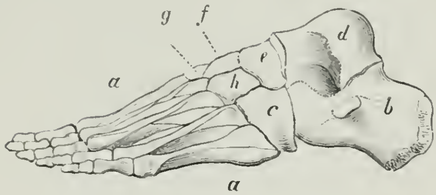


FIG. 4.—BONES OF HUMAN FOOT.

a a, metatarsals; b, calcaneum; c, cuboid; d, astragalus; e, scaphoid; f, middle cuneiform; g, internal cuneiform; h, external cuneiform.

and ankle respectively; the bones immediately above them to those of our forearm and leg. The human forearm consists of two separate bones—the *radius* and the *ulna*, the former being capable of a certain amount of rotary motion. Its upper end revolves upon its own axis; the lower end, next the hand, moves to some extent round the ulna, and as a consequence the hand can be turned while the elbow remains fixed. The forearm of the horse contains but one distinct bone; a portion of this, however,

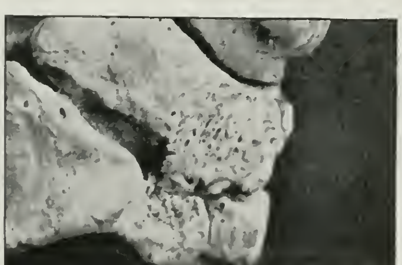


FIG. 5.—PART OF HOCK OF HORSE SHOWING "SPAVIN."

This disease makes the bones of the hock become spongy, and in extreme cases causes them to unite, so that a stiff joint is the result.

represents the upper end of the ulna. The ulna has evidently become fused with the radius, and a part of it has disappeared. In the human hand five long bones extend from the wrist through the palm and terminate at the bases of the digits, which answer to the five toes of mammals previously mentioned, the thumb being No. 1. The bones below the knee of the horse correspond to the middle bone of the palm and the three bones of the middle finger; the long, strong, upright *cannon* bone answers to the bone of the palm, the sloping *pastern* bone, and the *coronet* and *pedal* bones—the last of which is encased in the hoof—to those of the finger.

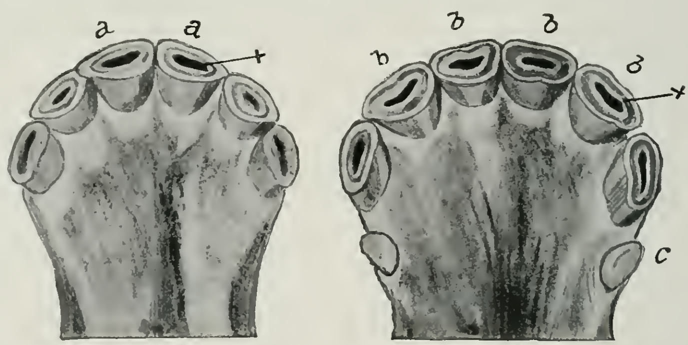


FIG. 6.—HOW TO TELL THE AGE OF A HORSE BY ITS TEETH.

A, teeth of a colt; B, teeth of a horse 4–5 years old.
a a, b b, permanent incisors; x, marks on incisors; c, "canines."

The horse walks upon the tip of the middle finger, which is encased in a strong box, the hoof, formed by the much thickened and enlarged finger-nail. On each side of the cannon bone, and fused to it, is a slender bone known as a splint bone, the lower extremity of which, about two-thirds down the cannon, is the location of the unsoundness to which these bones give their name. These splint bones are vestiges or remains of toes Nos. 2 and 4. Nothing answering to toes No. 1 and 5 is present.

The bones of the hind limbs of the horse bear practically the same relation to those of man's lower extremities as his fore limbs bear to the arms and hands. The point of the hock corresponds to the

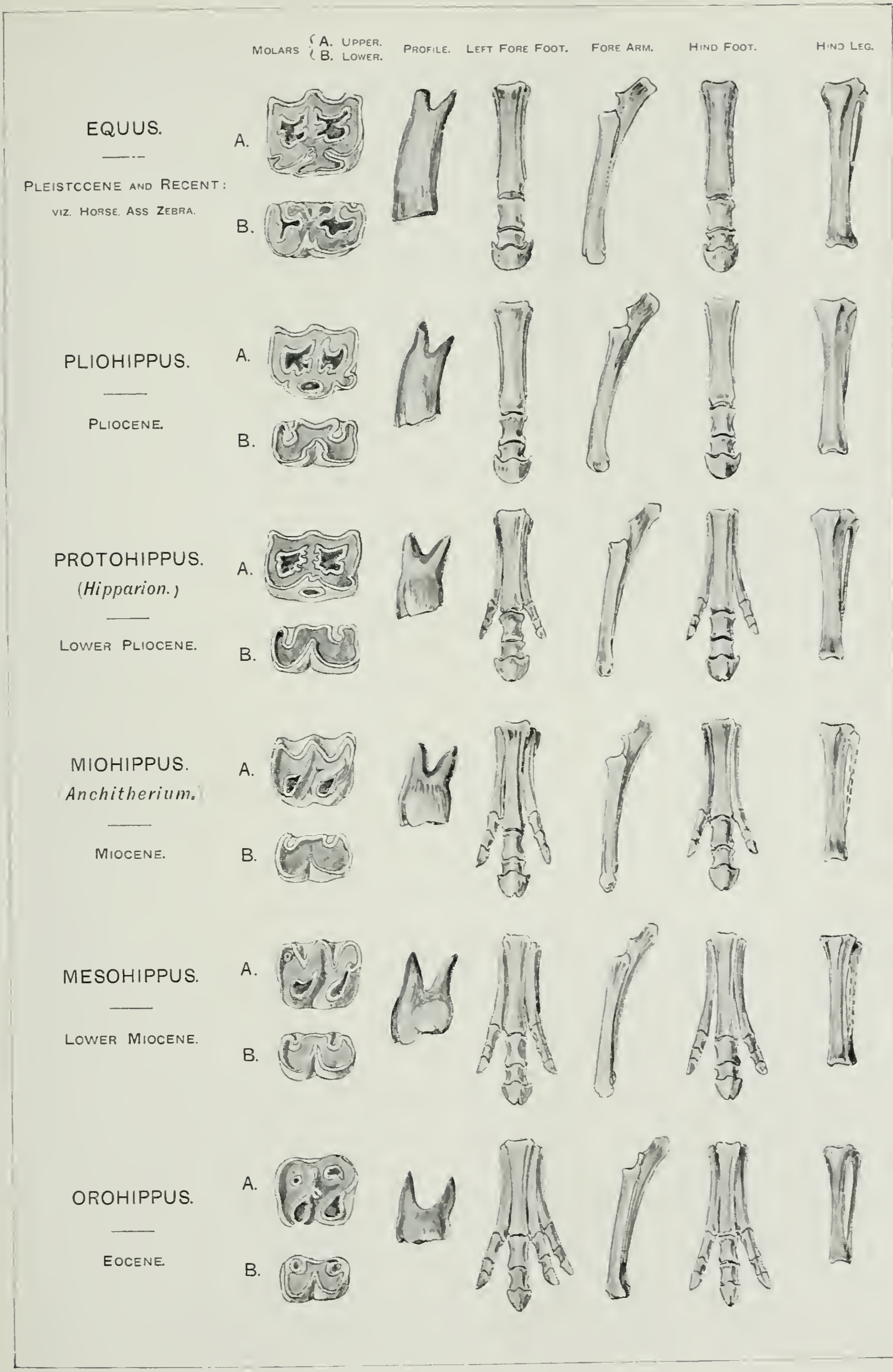


FIG. 7.—THE EVOLUTION OF THE HORSE AND ITS NEAREST RELATIVES THE ASS AND ZEBRA.

Some authorities hold that the horse as we know it to-day has two distinct lines of descent—the Old World and the New. The latter is more complete than the former.

FIG. 8.—AMERICAN TROTTER.

Like the racehorse, the development of this breed has been in the direction of speed. Compare size and shape with Figs. 9 and 10.

human heel, and the bones below it, starting with the cannon bone, are the same in number and similar in form to those below the knee of the fore limb.

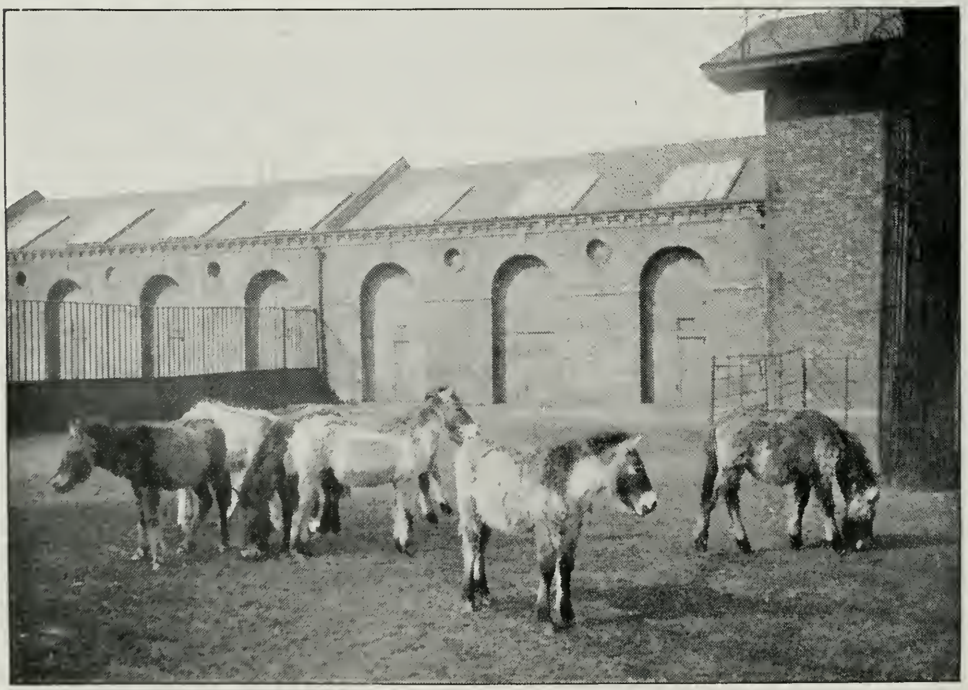


Photo: Cassell & Co., Ltd.

FIG. 9.—WILD HORSES OF THE ASIATIC STEPPES.

Compare with Figs. 8 and 10

It gives considerable support to the theory of evolution that in 1877 Huxley should have anticipated what has since actually occurred—namely, that when the rocks of the earlier Eocene period and the still older ones belonging to the Cretaceous epoch had been more thoroughly examined, and had yielded up their remains of ancestral equine animals, there would be found "first a form with four complete toes, and a rudiment of the innermost, or first digit, in front, with probably a rudiment of the fifth digit in the hind foot; while in the still older forms the series of digits will be more and more complete, until we come to the five-toed animals, in which, if the doctrine of evolution is well founded, the whole series must have taken origin." This expectation has been fulfilled by the discovery in America of well preserved remains of several species of an animal which has been named *Phenacodus*. Each limb had five hoofed toes, and though the size of the animal varied considerably, the largest were only about the size of sheep. A little more advanced in the stage of evolution is *Hyracotherium*, remains of which have been found in this country. The largest specimens were not so large as those of the *Phenacodus*; there were four toes reaching to the ground, or nearly so, on the fore limb, No. 1 being much reduced, and three functional ones on the hind limb, Nos. 1 and 5 being reduced. A study of the animal remains of the rocks of the same and of a somewhat later period than those yielding *Hyracotherium* shows that many similar forms—animals built upon the same general plan and probably offshoots from it—existed during that time.

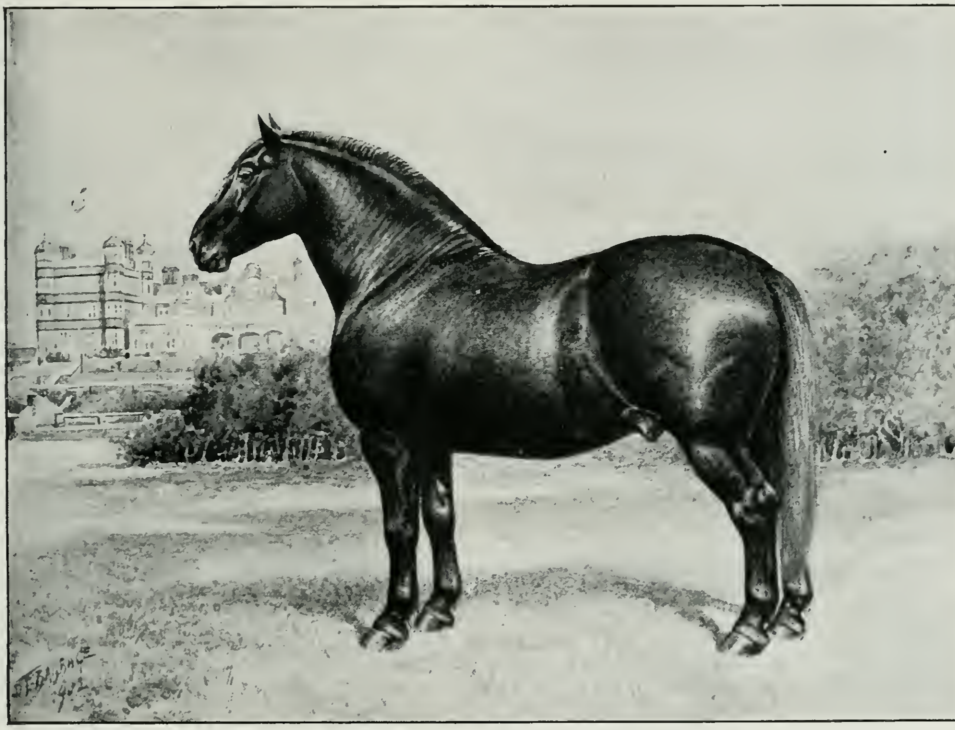


FIG. 10.—SUFFOLK CARTHORSE, "PRINCE WEDGEWOOD."

This noble animal, the property of Sir Cuthbert Quilter, Bart., M.P., shows how highly evolved in the way of strength and size the English breeds of carthorse are. The compact, clean-legged Suffolks are the oldest and purest breed in the country, with the exception of the Arab thoroughbred.

Many of these became extinct within a comparatively short period, while others lived on and underwent various modifications in the structure of many parts of the body; some have existed to the present day, and are now the hoofed animals we possess.

Fig. 7 illustrates the stages in the reduction of the number of toes, and the alteration in the form and the relative size of the bones of the fore-arm and leg —in the earlier forms they were distinct —as well as the changes in the character of the teeth, which have occurred in the evolution of the horse from this period. The teeth of the animals mentioned in the lower part of the figure were not nearly so well adapted as those of the horse for dealing with hard or tough substances. Their *incisors* or cutting teeth were somewhat chisel-shaped, and consisted of an outer covering of enamel surrounding a core of ivory. The *molar* or grinding teeth were short, and their free surfaces very irregular. In the course of evolution the incisors have been strengthened and rendered more efficient. In a young horse there is, in addition to the outer coating of enamel, a ring of the same hard substance surrounding a pit in the upper surface of the tooth. This pit gradually disappears as the surface of the tooth wears down; while it lasts it is of service in judging the age of the animal. In much the same way the *molars* have been improved for their function. They have been lengthened, and the deep valleys of the free surfaces filled up with comparatively soft material, so that they now present an admirable grinding surface of varying degrees of hardness.

Fig. 7 also shows the geological period of the deposits in which the remains of the animals referred to occur; the lowest, the Eocene, is the earliest, and the others follow in chronological order. The list of animals given does not include all those known in the line of descent; there are intermediate forms, and others are from time to time brought to light. It is not suggested that any one of these forms sprang directly, or even in the course of a few generations, from the preceding one; undoubtedly the process of evolution must have been slow, for the power of heredity would be great, and innumerable generations must have occurred between any two of the forms illustrated.

That the horse has developed along the lines indicated above is supported by evidence other than that of fossils. In the upper part of the nostril of members of the horse family is a blind pouch known to veterinary surgeons as the *false nostril.* Its function is not known, but the fact that a similar structure occurs in tapirs and rhinoceroses is a further indication that these animals had a common ancestry. All the early Ungulates had seven grinding teeth on each side, above and below. In the horse family the normal number is six, but occasionally an extra small one appears in front of the others. In the earlier animals the front grinding tooth was well developed, but in the later ones it became less and less, until in the horse it altogether disappeared. The occurrence of these small teeth appears to be a case of the reappearance of a lost part, and as such is a further point in the evidence of the horse's descent.

It has been suggested that the wart-like excrescences which always occur on the inner surfaces of horses' limbs, a little above the knee in the fore limb and below the hock in the hind one, and which are commonly known as "chestnuts," are rudiments of toe No. 1. In horses they are always present from birth to old age, and those of the fore limb are common to the whole horse family, though sometimes they are present in a modified form, but in spite of their constant occurrence their function

or use is quite unknown. It is most unlikely, however, that they represent in any way toe No. 1, as those of the fore-legs are situated too high, being above the knee, and underneath the skin no indication occurs of anything similar to a toe.

We are naturally inclined to speculate as to what factors influenced the development of the horse and his closest allies along the lines indicated, and upon this subject much information of a helpful character may be gained by a study of the habits of these animals when they exist in a free state at the present day. They always inhabit open plains, where the food is often dry and difficult to masticate, never forests or swamps ; and for the means of protection from their enemies they depend upon their senses of smell, sight, and hearing—all of which are very keen—upon their great speed, strength, and endurance, and lastly upon their great kicking power. The whole structure of the members of the horse family is such as admirably fits them for the life they lead. Their nearest relations—the tapirs and rhinoceroses—inhabit swampy districts and exist under entirely different conditions, and there can be no doubt that the series of changes through which the horse tribe has passed in its descent is a case of adaptation to altered conditions of life. The limbs are well suited to rapid movement over hard ground, where a number of expanding toes, although useful for supporting a heavy animal on damp, swampy ground, would be no advantage, but rather the reverse. The structure of the teeth enables them to deal effectively with the dry and harsh substances which during a large part of the year form their natural food, and thus secures them the nourishment which is essential for their maintenance.

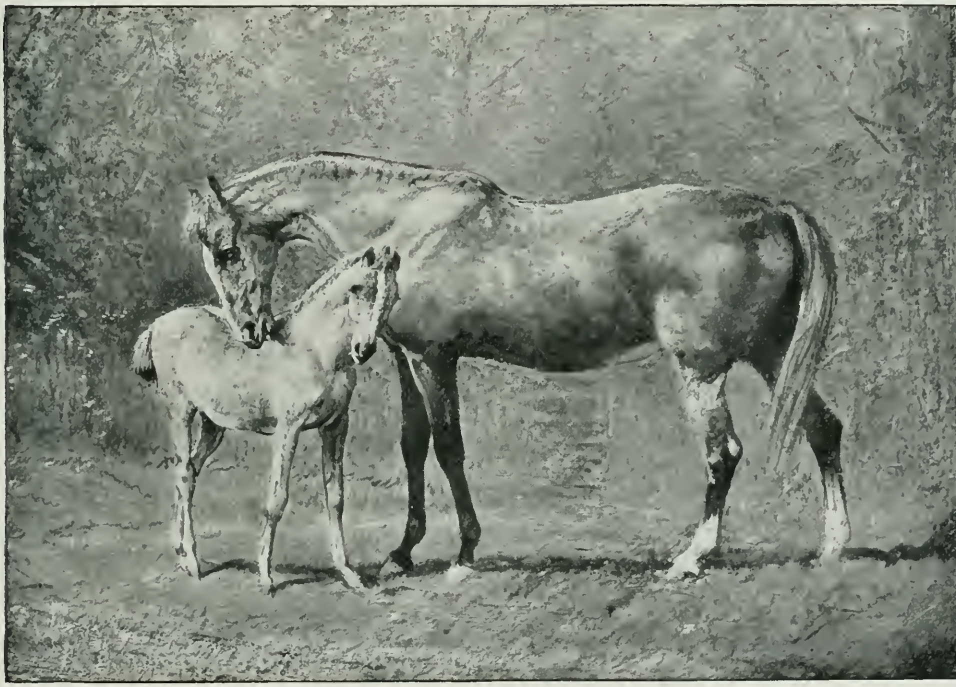


FIG. 11.—THOROUGHBRED MARE AND FOAL.

The modern thoroughbred is unequalled for elegance of build, and has a remarkable turn of speed.

It is a disputed point whether or not there are in existence now any truly wild horses whose ancestors have never been domesticated. That horses were at one period very abundant in America is proved by the presence of their remains, but it is generally admitted that they had become extinct before the commencement of the historic period, though it is difficult to understand how their extinction was brought about in a country which was evidently well suited to them, judging from the size and numbers to which they once attained, and in which they thrive at the present day. The wild horses which have roamed over the American plains in recent times are believed to have all descended from animals escaped from captivity. A variety known as Prejevalskii's wild horse, which occurs on the steppes of Western Asia, is considered by some authorities to be a truly wild form, whose ancestors were never subjugated by man; others, however, maintain that it is descended from "escapes," and its origin is certainly somewhat doubtful. If it is not a really wild form, it is probably the nearest approach to it that now exists.

FIG 12.—SHETLAND PONIES.

It is, of course, impossible to say what may be the future development of the horse. That he will undergo further important changes is very probable, but any changes that would interfere with his usefulness to man will be checked as far as possible by artificial selection, while any that would tend to increase his utility will be favoured by the same means. From quite early times horses have been divided into distinct breeds or varieties, differing in size, strength, speed, form, and other qualities. In the first place, these differences were no doubt largely due to the districts in which the animals were reared, more particularly the abundance and quality of the food they provided. But horses are now generally kept under more or less artificial conditions, so that this influence is reduced to a minimum, and the one important factor determining the development of a breed is the selection of breeding animals.

The great modifications of which the horse is capable, with the guiding help of man, are exemplified by the massive "feathery" shire horses, by the swift and spirited thoroughbred race-horses and their relatives the American trotting horses, as well as by the diminutive Shetland pony.

HOW MEN WORK UNDER WATER.

By T. C. HEPWORTH.

ALL good swimmers know how to dive, and they have no difficulty in opening their eyes under water and seeing sufficiently well to pick up any prominent object—such as a coin—from a depth of several feet. Men have dived in this way from time immemorial, and we may be quite sure that in warm climates—and more especially in countries where subaqueous exploration would offer any kind of reward—savage man might be almost regarded as being a naturally amphibious animal.

Photo: T. C. Hepworth.

FIG. I.—THE PRINCIPLE OF THE DIVING-BELL.

An empty glass is inverted in a vessel filled with water. As long as the glass is kept to the vertical the contained air cannot escape, although the deeper the glass is submerged the greater will be the pressure upon the air.

Hunger would probably suggest the first essay in search of edible shell-fish, and later on that strange desire for ornamenting the person with anything coloured, sparkling, or iridescent would prompt the search for pearls and coral. In time these would be sought, as would sponges, for purposes of commerce, and men would become expert in an art which in the first case was little more than a pastime.

Romance always lingers around that which is unknown, and the ancients peopled the unexplored depths of the waters with syrens, mermaids, and other fanciful creatures; but in these more prosaic days, although our excursions beneath the waters are of necessity extremely limited, we can ascertain by means of deep-sea soundings the general condition of things miles below the surface of the sea.

There have been handed down to us wonderful stories of the length of time for which certain men have remained under water. Most of such stories are good examples of the art of exaggeration, for although by training a man may be able to hold his breath for perhaps ninety seconds or so, the majority of mankind are so constituted that they must inflate their lungs at much shorter intervals of time.

This fact must have been realised, and possibly accentuated by many a fatal accident, before men thought of assisting the diver by some apparatus which would enable him to increase the time for which he could remain under water. The diving-bell appears to have been the first contrivance of the kind, and something of the sort is alluded to by Aristotle, who flourished some three hundred years before the Christian era. The diving-bell was employed in searching for the wrecked

ships of the Spanish Armada at the end of the sixteenth century, on the coast of Mull, and may be said to have been in constant use ever since the dawn of the nineteenth century.

Its principle is roughly shown by inverting a tumbler in water (*see* Fig. 1). The contained air in such a vessel will keep the water out, and although, as the depth is gradually increased, the air space will grow less by compression, until at a depth of thirty feet it would be reduced to one-half, the air will be held prisoner there so long as its containing vessel is kept in a vertical position.

The first diving-bell, or "chest," as it was termed, was made of wood with metal hoops, just like a barrel, and was sufficiently weighted to counteract the buoyancy of the water. The air soon became polluted, and the practice was established of sending down to the diver frequent charges of fresh air by means of small barrels. In Evelyn's diary, under date May, 1662, we find an entry to this effect: "Went to Deptford to see a new diving-bell, made of lead, and let down into the water by means of a strong rope."

It was more than a hundred years later that Smeaton, the celebrated engineer, furnished the diving-bell with a force pump and tube by which the vitiated air could be continually replaced by fresh air, the pump being carried in a boat above the submerged bell. He, too, seems to have been the first to make the bell of cast-iron; it weighed $2\frac{1}{2}$ tons, and was large enough for the accommodation of two men. The diving-bell of to-day, although exhibiting many improvements, is of much the same pattern as that introduced by Smeaton.

The modern diving-bell is made of steel and has a ballast chamber, in which are carried cast-iron weights. It is fitted with speaking apparatus, so that those at work within it can communicate with those in charge of the shifting apparatus above, and can give directions as to any desired change of position. Bells of large size are furnished with air by means of powerful compressors worked by steam, and, if need be, electric lights add to the comfort of the men at work under water.

The prototype of the diving-bell may be found in nature in the beautiful little cocoon woven by the diving spider, *Argyroneta aquatica* (Fig. 2). This is bell-shaped, and is attached by silken threads to the weeds and other objects under the water of a pond, and the insect fills it with air by bubbles which it carries down with it until the bell is full. A few years back it became quite the fashion to keep these little creatures in aquaria.

The diving dress is a comparatively modern invention, and has only been brought to perfection within quite recent

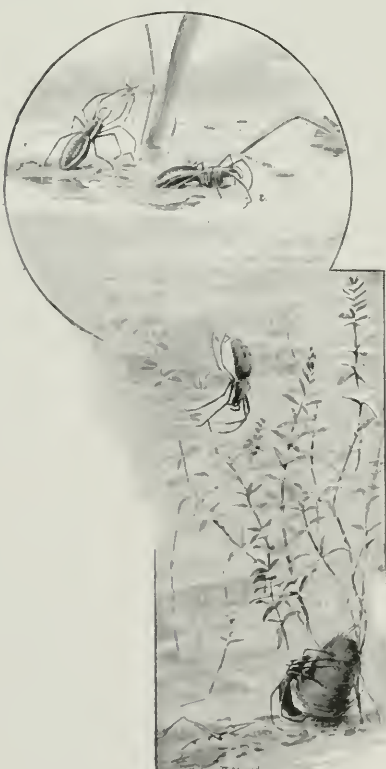


FIG. 2.—THE PROTOTYPE OF THE DIVING-BELL: THE DIVING SPIDER.

The "bell" of the diving spider is the cocoon seen at the bottom of the picture.

years. The most important part of a diver's equipment is the helmet, and the first one made for diving purposes was

Photo. T. C. Hepworth.

FIG. 3.—THE FIRST DIVING HELMET.

Compare with the modern patterns of helmet shown in Figs. 4 and 5.

invented by Siebe in 1819. A photograph of it is shown at Fig. 3. This helmet was riveted to the collar of the diving dress, which at that time did not extend below the waist. There was an ever-present danger to the diver in the use of this open dress, as it was called, for if he stooped while at his work the water would rush in from below, and he ran the risk of being drowned. The modern form of helmet (Figs. 4 and 5) is quite elaborate in comparison. The air, instead of escaping below the dress, has here an adjustable valve for its exit. There is also a telephonic attachment to the helmet, by means of which the submerged man can freely talk to those who are furnishing him with air, and can give them directions with regard to moving the boat above, in which the air-pump is placed, so as to give him a greater area in which to work. On the breastplate of the helmet shown in Fig. 5 there is an electric lamp, which is a necessity to the diver when his duties take him into the dark recesses of a wrecked ship, or into situations where the water is dirty, and therefore semi-opaque.

A modern diving dress is made of rubber throughout, and may be truly described as an overall, for it covers the figure completely, except the hands and the head. The wristlets of this dress are quite flexible, so that when the hands are thrust in no water can pass that way. The dress is furnished with a metal yoke or collar-piece, upon which the helmet can be readily screwed in place. The diver wears toe-protected boots, with leaden soles three-quarters of an inch in thickness, and before he enters the water a breast weight and a back weight, strung together by cords which go over the

FIG. 4.—A MODERN DIVING HELMET.

This is an elaborate contrivance, with adjustable air valves and telephonic attachments.

shoulders, are attached to him. Without these he would float like a bubble on the surface of the water, for both dress and

helmet are full of air. He can move about freely enough when in the water, but directly he comes out he feels the oppression of the weights by which he is encumbered, and he is glad enough to rely upon the good offices of his attendant to help him to lift his legs into the boat.

It has already been stated that exaggerated statements have been made as to the time for which a man is able, without apparatus, to remain under water. Similar misapprehensions have arisen with regard to the depth to which a man can safely go when furnished with the most complete diving gear. One hundred and fifty feet below the surface may be regarded as the greatest depth at which an ordinary diver can safely work. A man's body is not constituted to bear the great pressure which a lower depth would entail, but there have been exceptional cases in which men of extraordinary strength have gone to a depth of 200 feet. One of the most remarkable salvage feats ever performed by a diver was that of Alexander Lambert (in the employ of Messrs. Siebe and Gorman), who recovered from a depth of 180 feet several boxes of gold coin from the wreck of the steamship *Alphonzo XII.*, which sank off Las Palmas in 1885. The intrinsic value of the gold which he sent up to the surface in boxes was no less than £70,000.

Until recent years sponges were gathered from the submerged rocks in a somewhat primitive manner. There were, indeed, two systems employed, in one of which a man dived naked into the water, without any apparatus save a heavy stone attached to a rope to help him in sinking to the required depth, and in the other the sponges were torn from their habitat by means of a kind of trawl, attached to a sailing vessel. The diver equipped with modern apparatus can, of course, remain below water for a long time, and his harvest of sponges is proportionately large.*

Diving apparatus is also in use for the quest of that still more coveted marine product the pearl.†

The diving apparatus invented by Mr. Henry Fleuss formed the subject of a paper read before the Society of Arts in May, 1880, by the late Sir Benjamin Richardson. This form of dress dispensed entirely with the necessity for supplying the diver with air from any external source, for the wearer was enabled to breathe the same air over and over again.

In the Fleuss apparatus provision is made for replacing the oxygen absorbed by the lungs of the wearer, while at the same time the carbonic acid is rendered inert.

Two flexible tubes proceed from the mouth of the wearer of this dress, and are carried over his shoulders to a kind of knapsack on his back. One of these tubes is for inspiration and the other for expiration of the breath, and they are so fitted with self-acting valves that their duties cannot be reversed. If we trace the course of the expired air we shall find that it goes through a series of channels in the knapsack, which are filled with tow charged with lumps of caustic soda, which has the property of absorbing carbonic acid, so that the air proceeds to the inspiration tube robbed of this deadly constituent. But in its passage through the lungs it has lost part of its oxygen, and unless this were made good the man would quickly succumb. To supply this deficiency, there is carried just below the knapsack a small cylinder of compressed oxygen, and the wearer is enabled to turn on just so much of the gas as he requires to make up for that absorbed by his lungs. The same charge

* *See* "A Piece of Sponge," CASSELL'S POPULAR SCIENCE, Vol. I., p. 160.

† *See* "Pearls and Mother-o'-Pearl," CASSELL'S POPULAR SCIENCE, Vol. I., p. 398.

of air thus serves him for several hours, *plus* the oxygen which he obtains from the supply compressed in the cylinder.

This apparatus, it will be seen, is a very cleverly thought out application of scientific reasoning, and although it is not suitable for deep-sea work, when the question of pressure has to be considered, it is invaluable for shallow waters and in the exploration of places where there is an atmosphere which will not support life. It has been already used in mines after an explosion, and has been the means of saving many lives. It was also employed with signal success during the progress of the Severn tunnel construction, when the works became flooded by land springs, and it was necessary to proceed under water to a distance which would have been impossible if the diver had had to drag behind him an air-pipe. These works would have been altogether stopped had not the Fleuss apparatus been at hand at the critical moment.

FIG. 5.—A MODERN DIVING HELMET.
With electric lamp upon the breast.

A more recent French diving apparatus has been made on somewhat similar lines, but the compressed oxygen is replaced by a charge of sodium peroxide, which gives off that gas when immersed in water, means being adopted to drop the chemical into a vessel of water in minute quantities as required.

It is not, perhaps, generally known that all the larger vessels of the British Navy carry a staff of divers and complete apparatus for their use, and that there are schools for the education of naval divers at Portsmouth, Devonport, and Sheerness, while there is another for the study of submarine engineering at Chatham. Among the duties required of these naval divers may be named that of cleaning a ship's bottom when it has become covered with marine growth. Such a coating may have the effect of reducing the speed of a vessel by one half, and it quickly accumulates, especially in warm seas. The divers are slung over the ship's side, and by means of ladders, scrapers, and other appliances they are able to clean the ship's side of its burden very quickly.

Another task which occasionally falls to the lot of the divers on board one of His Majesty's ships is that of recovering an anchor which may have been lost. They are also sent down to report upon any damage which may have been caused by collision or otherwise to the hull of the vessel.

The first ship of the Royal Navy which ever engaged the attention of divers was probably the ill-fated *Royal George*, which went down at her moorings at Spithead one August day in 1782, with a loss of no fewer than 600 lives. The wreck was not surveyed by divers until sixty years later. A curious old print of the operations, which is so discoloured that

only an imperfect photographic reproduction of it can be given, is interesting, if only on account of its rarity (Fig. 6). Fig. 7 shows some of the relics recovered from the old warship. A bottle of soda water which the divers found in the wreck was sold the other day in a London auction room for more than twenty pounds.

embrace of the sea vessels which are submerged, and which would have been regarded only a few years ago as hopeless wrecks. The present article would be incomplete if it did not place on record some wonderful instances of salvage which have been successfully achieved during the past few years by the aid of

Photo: T. C. Hepworth.

FIG. 6.—DIVERS AT WORK UPON THE WRECK OF THE *ROYAL GEORGE*.

The "Royal George" went down at her moorings, at Spithead, in August, 1782.

divers. The salvors have brought to bear upon their efforts technical knowledge and mechanical appliances, without which their best endeavours would have been of no avail.

We have to deplore in this country alone an annual average of some 3,000 casualties to shipping on our coasts, one-sixth of the number representing total wrecks. These numbers, be it understood, refer only to the coastline of the British Isles, and take no note of maritime losses in other parts of the world.

But, although stories of shipwreck are so common and losses through stress of weather and collision so frequent, the average reader has little opportunity of learning the successful efforts which are now often made to recover from the

Let it be understood that, although the salvage of wrecked ships has been carried to a wonderful pitch of perfection, there is a limit with regard to the depth of a submerged vessel, beyond which it is useless to make any attempt at recovery. As an example we might cite the case of the noble warship the *Victoria*, which, it will be remembered, was rammed

by the *Camperdown* during some evolutions in the Mediterranean in 1893. The doomed ironclad sank with most of her crew in seventy fathoms of water, and all idea of recovering her, or any part of her equipment, from such a depth was simply out of the question. The depth, in fact, in which anything can be done towards salvaging a submerged vessel is limited to that to which a diver can descend without risking his life, and this depth, as we have seen, may be placed at 150 feet.

The initial operation is to send down a diver to report upon the position of the wreck, and the amount and character of the damage which the hull has received. It will be evident that the *Victoria*, which represented a money value of something like one million sterling, was beyond human help, for she found her grave at a depth which would have engulfed St. Paul's Cathedral, with twenty feet of water still above its topmost point.

Let us take another case, also a vessel of His Majesty's Navy, but a sailing vessel, the *Eurydice*. This ill-fated ship sank in such comparatively shallow water that the divers were able to visit her.

The first thing to be done was to moor two buoyant vessels, or pontoons, just above the wreck, and these were connected by girders formed of heavy baulks of timber. To these massive timbers were attached wire cables, which at their lower ends were fastened to the wreck (Fig. 8). At high tide these cables would be taut, but with the fall of the water they of course became slack. Everything being in readiness and the weather favourable, a day came when, at low tide, the slack cables were made taut, so that as the tide rose the wreck was pulled from its bed and hung suspended by the wire ropes to the pontoons. Gradually higher and higher swung the wreck, until the time of highest tide approached, when steam tugs, which had been in waiting, were attached to the pontoons, and pulled them towards the land. As the water became shallower, the wreck came nearer and nearer to earth, until she once more grounded on the sea bottom. Again did the salvors wait until low tide came, the wire ropes were once more shortened, and once more at high tide the *Eurydice* was drawn towards Portsmouth, to ground at such a depth that her whole hull was

Photo: T. C. Hepworth.

FIG. 7.—RELICS RECOVERED BY DIVERS FROM THE WRECK OF THE *ROYAL GEORGE*.

visible at low water. This was her last berth, and there she was broken up.

The *Puffin*, the lightship which guarded Daunt's Rock a few miles outside Cork Harbour, foundered with all hands during a terrible gale in October, 1896, in ninety feet of water. She was brought to land in the same manner as that described in the case of the *Eurydice*, only that in view of her smaller bulk a single hulk was employed for the suspending wire ropes.

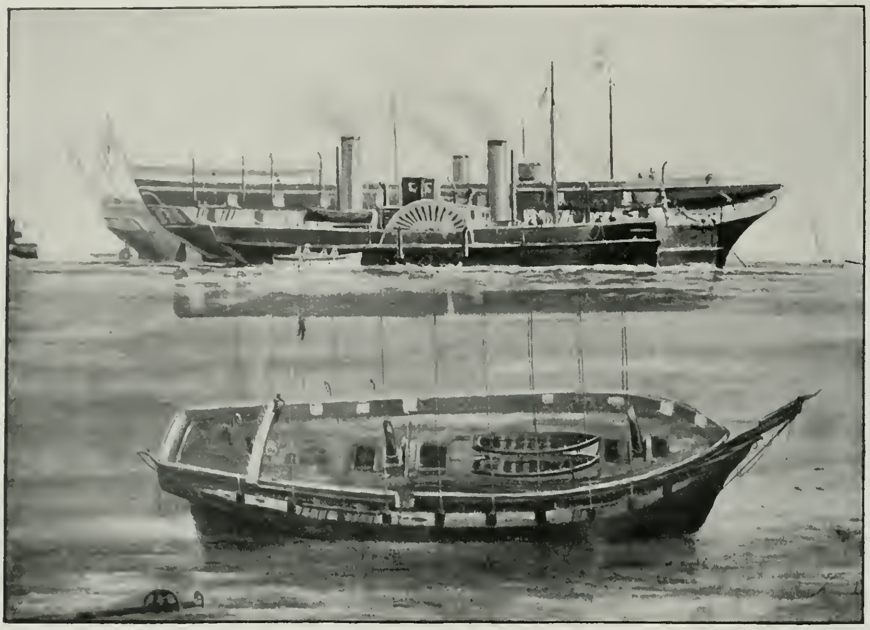


FIG. 8.—HOW H.M.S. *EURYDICE* WAS RAISED.

(From a copy of an Oil Painting in the possession of Messrs. Siebe and Gorman.)

The tough wire ropes which brought the ill-fated vessel from her oozy bed can be plainly seen.

A far more difficult problem was that presented by the *Umatilla*, a steamship which grounded on some sunken rocks at Esquimault, and became, to all intents and purposes, a hopeless wreck. The divers' report was not encouraging; a huge slice was torn off the stem of the vessel, and her hull was as full of holes as a colander. But the holes were stopped, a solid partition was built up inside the hull to cover the breach in the stem, and preparations were made to pump the water out. But it was foreseen that, owing to the depth of water above the deck, if that beneath it were replaced by air, the deck would probably cave in by the pressure above it. It was therefore determined to build up a structure of wood above the deck, so as to extend the vessel's sides to above high-water mark. This was the more difficult to accomplish on account of the vessel having a heavy list. But the work was done. The heavy wooden structure was built up piece by piece by divers, and one would have imagined that skilled carpenters working under ordinary conditions had accomplished the task, so well was it performed. Then pumps were set to work, each capable of discharging 150,000 gallons per hour, and the ship once more floated. She was thoroughly repaired, and is now as good as ever.

Let us take another case where a

vessel was saved by the timely use of these powerful centrifugal pumps. A few years ago the steamship *Dahomey* went ashore near Holyhead, her hull being greatly damaged by the rocks. In this case the difficulties of salvage were enormously increased by a fire which broke out amongst the cargo in the forward part of the ship. The salvors had to grapple with fire and water at the same time, but pluck and determination overcame all obstacles, and the vessel was ultimately saved. Divers went down, in the first place, to stop all leaks. Then the pumps were taken aboard and emptied the vessel of the thousands of tons of water which she contained, but the water had not, strange to say, reached the cargo forward, which was still burning. At last the wreck fairly floated, and was taken to Holyhead to be put into a thorough state of repair.

Landsmen are apt to regard an iron ship—and most ships are built of iron nowadays—as something so strong and impervious to hard knocks that it will stand a good deal of buffeting. But this is not the case. The iron skin of an ordinary merchantman is far thinner in proportion to the bulk of the ship than is an eggshell in proportion to the entire egg. But let us put the matter more definitely. The eggshell is about one hundredth part of the diameter of the egg, and if we were to give a ship of, say, thirty feet beam an iron skin of the same proportionate size, that skin would measure more than $3\frac{1}{2}$ inches in thickness, instead of the $\frac{1}{4}$ inch which is considered sufficient for the purpose.

It is evident that a massive thing like a ship, with such a very thin crust, must be handled with great care, for a comparatively light contact with another vessel is quite sufficient to do serious damage.

Should a ship founder through an injury of this kind, and lie within the limit possible for diving operations, the rent will be covered by a wooden shield, and the vessel, after having been pumped out, will rise to the surface, and be taken for more permanent repairs to the nearest available port.

FIG. 9.—BROKEN IN TWO PIECES.

See Fig. 10 for the way in which this wreck was dealt with.

By permission of the Liverpool Salvage Association.

Of the great work accomplished by divers in the construction of breakwaters and harbours I have no room to speak. Such works are often of the most colossal character, and the magnificent harbour which is now in course of construction at Dover may be cited as an instance. Such a work would be impossible unless strong foundations were laid below water by divers.

FIG. 10.—PATCHED AND FLOATED.

The wreck was patched up in two halves by divers, each half was raised independently and finally placed together again. Compare with Fig. 9.

By permission of the Liverpool Salvage Association.

TOTAL ECLIPSE OF THE SUN, JULY 28TH. 1851, AT BUE ISLAND, NORWAY.

TOTAL ECLIPSES OF THE SUN ARE RARELY SEEN IN THIS COUNTRY. WHILE THE LIGHT IS VERY DIM, THE SKY ITSELF GLOWS WITH RICH RED AND ORANGE HUES, AND THE CONTRAST IS VERY WEIRD. THE PLATE SUGGESTS SOMETHING OF THIS.

(From a Painting by the late Professor Piazzi Smyth.)

AN ECLIPSE OF THE SUN.

By W. F. DENNING, F.R.A.S.

PRE-EMINENTLY calculated, from the striking nature of their aspect, to form one of the grandest sights in nature, it is not to be wondered at that total solar eclipses have been the source of amazement to the uninformed and the subject of frequent allusion by the historian; and it is unfortunate that a spectacle of this kind is so rare that comparatively few people have ever witnessed it. Unless a person is privileged to accompany an expedition specially equipped to investigate and record one of these occurrences, or unless he chances to reside on that particular tract of the earth's surface over which the line of totality passes, he will never, perhaps, have the opportunity of witnessing this grand celestial sight. It is not because a total solar eclipse is a phenomenon which rarely happens that it is but seldom observed, for if we consult a catalogue of eclipses we shall find at once that they are of somewhat frequent occurrence. It is rather because they are visible only from a very limited area of the earth's surface that they form an event of exceptional rarity; so that if we await the phenomenon at any particular station many generations may pass without the expected gratification afforded by the view of so striking an occurrence. If we desire such an observation, we must go to the eclipse, and not wait until it comes to us. Englishmen who do not travel have not seen a total eclipse of the sun since 1724, for though many times subsequently to that remote epoch the sun has been largely hidden, it has never been absolutely obscured in total eclipse to observers in this country.

It is not difficult to understand that in ancient times, when extremely vague ideas prevailed with reference to natural phenomena, eclipses filled mankind with a good deal of superstitious terror. A gloom as of premature twilight descended upon the earth unexpectedly and suddenly, and men stood amazed at the unwonted withdrawal of the source of light. Weird shadow-bands fell over the landscape, giving earth and sky alike an unnatural aspect. As the darkness deepened the planets and brighter stars began to shine as at evening, birds went to roost, and the animal and vegetable world was influenced as at night. What stupendous influence could have thus so completely robbed the sun of his lustre? What dark body was that which, encroaching at first merely as a notch upon the sun's west limb, had gradually worked itself over the whole surface, until the usually dazzling sphere was obliterated and effaced from the heavens? Would this spectral darkness be yet further intensified and sustained, or would the sun be able to relieve himself from the incubus of the overshadowing monster? An appalling anxiety possessed the observers; but soon, as they tremblingly looked upwards again, the indications of returning day became apparent, the shadows began to be dispelled, as a slender crescent of the sun reappeared, increasing as time wore on, until, after a short interval, the solar orb completely freed himself, and the opaque obstructing body, whatever it was, wholly disappeared. All fears were relieved—the oppressive darkness dispersed, and animate nature quickly resumed her customary avocations. The coloured plate shows a little of the curious shade effects observed in Norway during the total eclipse in 1851.

Let us proceed at once to the simple explanation of the theory of solar eclipses.

A self-luminous body, like the sun, scatters light in all directions, and when the rays fall upon a non-luminous body they are intercepted from the space immediately behind it, so that a shadow is thrown a certain distance in that direction. Now, another celestial body, deriving its light also from the sun, will, upon entering the area over which this shadow is cast, manifestly be deprived of its lustre and suffer obscuration, either wholly or in part, during the entire period of its immersion. This is what happens to the earth in the case of a solar eclipse. The sun and earth revolve in the plane of the ecliptic, and the moon, being but slightly inclined to that plane, interposes between them once in every revolution (*i.e.* at new moon), so that it happens they are sometimes all three in the same line. When this occurs, a portion of the moon's opaque sphere is seen projected upon the sun's face, intercepting his light in a degree proportionate with the magnitude of the eclipse, which depends upon the distances separating the centres of the sun and moon at the middle of the phenomenon. Only in cases when these centres precisely correspond can there be a total obscuration, because the apparent diameters of the two bodies are nearly identical.

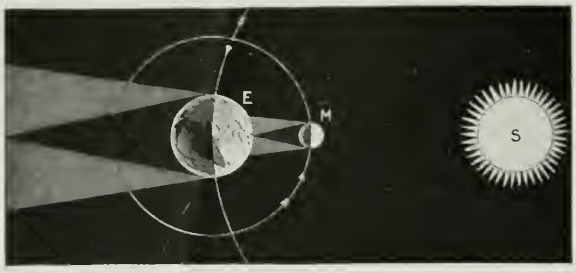


FIG. 1.—SHOWING HOW AN ECLIPSE IS CAUSED.
S, the sun; m, the Moon; E, the earth. Note the "umbra" and "penumbra" cast by the moon and the earth.

Let S (Fig. 1) represent the sun, M the moon, and E the earth. The two latter bodies being non-luminous, each projects shadows termed the umbra and penumbra. The umbra is a dense shadow; any object becoming immersed in it suffers total eclipse. The penumbra is a fainter shadow, giving partial eclipse. During a total eclipse of the sun, the moon (M), being very slightly greater in apparent size than the sun, throws her dark shadow only upon a small area of the earth's surface situated in the central line of the eclipse. The outlying penumbra covers a far greater expanse of the surface, giving a partial eclipse everywhere within its limits.

The sun would suffer eclipse at every new moon (at intervals of 29½ days) were the orbit of the moon situated in exactly the same plane as the ecliptic, but the inclination amounts to some 5°; hence the moon at conjunction frequently passes above or below the sun, and thus the necessary conditions of an eclipse are evaded. It is when the moon crosses the ecliptic at the time of the new moon that a solar eclipse must result, inasmuch as her position is then precisely between the earth and sun.

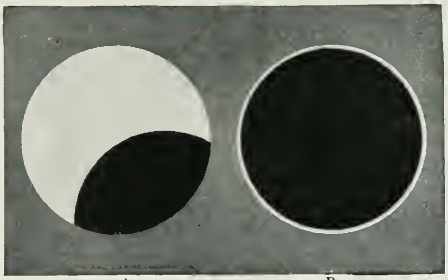
FIG. 2.—AN ANNULAR ECLIPSE.
S, the sun; M, the moon; E, the earth.

The word *eclipse*, as applied to these obscurations of the sun, is sometimes questioned as not being strictly accurate—for a celestial body when eclipsed must be immersed in a shadow. Now, we have just shown that a solar eclipse is caused by the projection of the moon's dark body upon the sun, which is equivalent to an *occultation* in cases of total eclipse;

but when the apparent diameter of our satellite is less than that of the sun, as in annular eclipses (Fig. 2), the event is really a *transit* of the moon across the sun. In annular eclipses the moon's dark shadow falls short of the earth, as in the figure, for the moon, being less in visible dimensions than the sun, cannot wholly intercept his rays, and only a partial eclipse results.

The Chaldæan shepherds foretold eclipses, even before the nature of such phenomena was thoroughly understood, by their regular recurrence after a certain interval. The moon's "nodical revolution" is performed in 27 days 5 hrs. 5 min. 36 sec., which is more than two days shorter than her "synodical period" (or the time occupied in passing from one new or full moon to another) of 29 days 12 hrs. 44 min. 3 sec. Now, 223 of the latter periods extend to 18 years 10 days and $7\frac{3}{4}$ hrs. (or 6,585·32 days), and 19 revolutions of the sun are performed, with regard to the lunar nodes, in 6,585·77 days. The correspondence of the two periods originates the recurrence of eclipses, both solar and lunar, at intervals of 18·03 years. This period was known as the *saros*. By adding it to the date of an observed eclipse the approximate date of its repetition was readily computed, though it must not be supposed that it supplied the data for determining the magnitude of the eclipse, as the conditions are slightly different at each recurrence; nor in the case of solar eclipses which are observable only from small tracts of the earth's surface was it possible by the aid of this cycle to foretell the particular locality over which the moon's shadow would be cast. But in a general way the method was found both convenient and accurate, and for many ages the ancients successfully availed themselves of its means to predict the times of these phenomena.

At each return the varying conditions of an eclipse affect the magnitude, so that it either increases or diminishes at each repetition. Those eclipses of the sun which occur at about the descending node, and are visible at first from the earth's South Pole, creep northwards at their successive returns, until ultimately they quit the earth at the North Pole. And the reverse is the case with those eclipses which, taking place near the ascending node, come in at the North Pole of the earth, for they gradually, at each recurring



A B

FIG. 3.—A "PARTIAL" (A) AND AN "ANNULAR" ECLIPSE (B): A COMPARISON.

saros, become more southerly, until their final disappearance off the South Pole. Thus a very small eclipse came on at the North Pole on June 24th, 1313, O.S., which finally leaves the earth on July 31st, 2593, after seventy-two occurrences. To illustrate the matter further let us refer to the eclipse of July 14th, 1748.* "This eclipse, after traversing the voids of space from the creation, at last began to enter the *terra Australis incognita* about eighty-eight years after the Conquest, which was the last of King Stephen's reign. Every Chaldæan period it has crept more westerly, but was still invisible in Britain before the year 1622, when on April 30th it began to touch the south part of England at about two in the afternoon. Its next visible period was after three Chaldæan periods, in 1676, on June 1st, rising central in the Atlantic Ocean, passing us at about nine a.m., with four digits eclipsed. It was visible

* "Ferguson's Astronomy" (1772), pp. 232–33.

again in 1694 in the evening, and in 1730 (July 4th) was seen above half eclipsed just after sunrise. Eighteen years more afforded the eclipse of 1748 (July 14th). The next visible return was in 1766 (July 25th), about four digits; and after two more periods, in 1802 (August 16th, O.S.), about five digits. Again in 1820 (September 1st, N.S.) it recurred as a large partial eclipse, and was well observed in England, the sky being generally clear. It was not visible again until 1874 (October 10th), five digits. In 1892 the sun went down eclipsed at London, and again in 1928 (November 12th) there will be two digits obscured at London. But about the year 2090 the whole penumbra will be worn off, whence no more returns of this eclipse can happen till after a revolution of 10,000 years."

Partial eclipses (Fig. 3, A) are those in which a segment only of the sun's face is hidden by our satellite at the time of greatest obscuration, when she passes either a little above or below the sun's apparent centre. They may be large or small, according to circumstances, and are usually expressed in digits or twelfth parts of the solar surface, so that an eclipse of three digits notifies an obscuration of a quarter of the sun, of four digits one-third of the sun, of six digits one-half of the sun, and so on. The "Nautical Almanac," however, gives more precise details of the magnitude of eclipses, the sun's diameter being considered equal to 1, while the portion eclipsed is represented by thousandths. There was a partial eclipse of the sun on May 28th, 1900, when the extent of the obscuration amounted to 0·681, or nearly seven-tenths of the whole.

Annular eclipses (Fig. 3, B) refer to those in which a marginal ring of the sun's disc is visible, though the apparent centres of the sun and moon correspond exactly in position. In fact, the apparent diameter of the moon being slightly less than that of the sun, it must fail to completely obliterate his luminous disc, and there is still a narrow circle of light visible all round the border indicating this. The sun when nearest the earth has an apparent diameter of $32\frac{1}{2}$ minutes of arc, and the moon at *apogee*—*i.e.* at her greatest distance from the earth—is less than $29\frac{1}{2}$, so that if a solar eclipse happens under these conditions it must essentially fail to be total. On the other hand, the moon at *perigee*—when she is nearest to the earth—subtends an angle of $33' 31''$, and the sun at greatest distance (when the earth is in *aphelion*) one of $31' 32''$, so that an eclipse occurring with these circumstances may be total if the centres of the two bodies exactly overlie at the instant of conjunction.

"Baily's beads" (Fig. 4) is the name given to a phenomenon sometimes observed at second or third contacts in total or annular eclipses, when the very narrow crescent of the sun is seen separated into a number of bead-like appearances—bright points alternating with dark spaces all along the limb. They were first described by Mr. Francis Baily during the annular eclipse of 1836, and hence acquired the appellation of "Baily's beads." The phenomenon has been thus explained. The contour of the moon is not perfectly circular, for as seen projected upon the sun in solar eclipses it presents a serrated or jagged outline, due to the mountainous nature of her surface; and it is obvious that as this serrated figure steals closely towards the sun's interior margin the dark mountain peaks will first envelop it, while the intervening valleys will still allow fragments of sunlight to be discernible. This must occasion a series of luminous points on the affected limb, giving rise to the bead-like appearances so often described by observers.

Mr. Dunkin observed the total eclipse of July 28th, 1851, at Christiania, Norway,

and thus describes the apparition of "Baily's beads," which he recognised both before and after the total phase :—"About fifteen seconds before the beginning of total darkness the narrow line of the sun broke up into numerous small

FIG. 4.—A "BEADED" ECLIPSE.

Note the bright points alternating with dark spaces on the edge of the sun's crescent to the left of the figure.

particles or beads of light. They were of different sizes, some being merely points, while others appeared elongated. Their appearance was of intense brilliancy, and the only thing with which I can compare it is a necklace of diamonds. The effect on the mind at their formation was quite overpowering. I was unprepared for so magnificent a sight. At the reappearance of the sun the same general appearance of the phenomenon was exhibited, but the effect on the imagination was not so striking, though the brilliancy of the 'beads' seemed equal to that noticed at the commencement of totality."

But the chief phenomena of these eclipses, and one having many important bearings, is the *corona*, or halo of light (which apparently surrounds the dark image of the moon), and the flaming red protuberances extending a considerable distance from the limb. The corona is undoubtedly a solar appendage produced by the receipt or discharge of masses of heated material by the great central luminary of our system. The corona appears to be composed principally of minutely divided matter of extreme tenuity, since comets experience no check in their rapid flights through it. The red flames or prominences seen on the sun's limb are sometimes clouds of hydrogen and other gases, apparently ejected from the sun with the enormous velocity of several hundreds of miles in a second of time. Professor Perrine, who observed the eclipse of May 18th, 1901, concluded that the outer corona consisted of reflected sunlight, while the inner corona emanated from incandescent gaseous matter ejected from the solar surface at a very high rate of velocity. Other observers, however, favoured the view that reflected sunlight entered very little into the composition of any part of the corona observed in 1901. It is to be hoped that future eclipses will assist in solving the various problems involved, and that observers will ultimately arrive nearer unanimity in their efforts to interpret one of the most striking occurrences of nature. There is no doubt that the form of the coronal extensions vary in sympathy with the condition of solar activity as displayed in the prevalence or paucity of sun spots. In fact, coronæ have been classified according to their marked differences of type at the maximum and minimum periods of sun spots. At the former period the corona seems to be developed indifferently in any direction. But, when the spots are few, the whole aspect changes, for "north and south a series of short, vivid, electrical-looking flame brushes diverge with conspicuous regularity from each of the solar poles, and the streamers, instead of being radial, are more or less parallel to the equator."

FIG. 5.

Showing the red flames A, B, C, D, seen round the sun when he is totally eclipsed, and the shallow red layer a, b, called the "chromosphere."

The number of eclipses in any year cannot exceed seven, or be less than two, in which case they are both of the sun. Solar eclipses are of more frequent occurrence than lunar eclipses, in the proportion of about three to two; yet the latter phenomena are more commonly observed, because they are visible from all parts of the earth's surface having the moon above the horizon, which includes an entire hemisphere, whereas the former are limited to a thin chord of the earth's surface, rarely exceeding 150 miles in breadth.

Total eclipses of the sun visible from some part of the earth's surface occur at the rate of about two in three years, as the following list will show:—

1880 ...	Jan. 11	1889 ...	Dec. 22
1882 ...	May 17	1893 ...	April 16
1883 ...	May 6	1896 ...	Aug. 9
1885 ...	Sept. 8	1898 ...	Jan. 22
1886 ...	Aug. 29	1900 ...	May 28
1887 ...	Aug. 19	1901 ...	May 17
1889 ...	Jan. 1	1903 ...	Sept. 20

The next total eclipse visible in this country appears to be that of June 29th, 1927, which will be best observable in the north of England, but totality will last only a few seconds. The next following that will be in 1999 (August 11th), total in the south-west corner of England. Others will succeed in 2090 (September 23rd), 2135 (October 7th), 2151 (June 14th), 2200 (April 14th), &c.

The largest solar eclipses of the present century visible in England will be as follows*:—

Year.	Date.	Middle.	Digits.
1905 ...	Aug. 30 ...	1 p.m. ...	10
1912 ...	April 17 ...	$0\frac{1}{2}$ p.m. ...	11
1914 ...	Aug. 21 ...	noon ...	8
1921 ...	April 8 ...	9 a.m. ...	10
1925 ...	Jan. 24 ...	$3\frac{3}{4}$ p.m. ...	7
1927 ...	June 29 ...	$5\frac{1}{4}$ a.m. ...	11
1945 ...	July 9 ...	2 p.m. ...	7
1954 ..	June 30 ...	$0\frac{1}{2}$ p.m. ...	10
1961 ...	Feb. 15 ...	$7\frac{1}{2}$ a.m. ...	11
1971 ..	Feb. 25 ...	$9\frac{1}{2}$ a.m. ...	7
1996 ...	Oct. 12 ...	$2\frac{1}{2}$ p.m. ...	7
1999 ...	Aug. 11 ...	10 a.m. ...	11

The greatest eclipses of the twenty-first century will be :—2015 (March 20th),

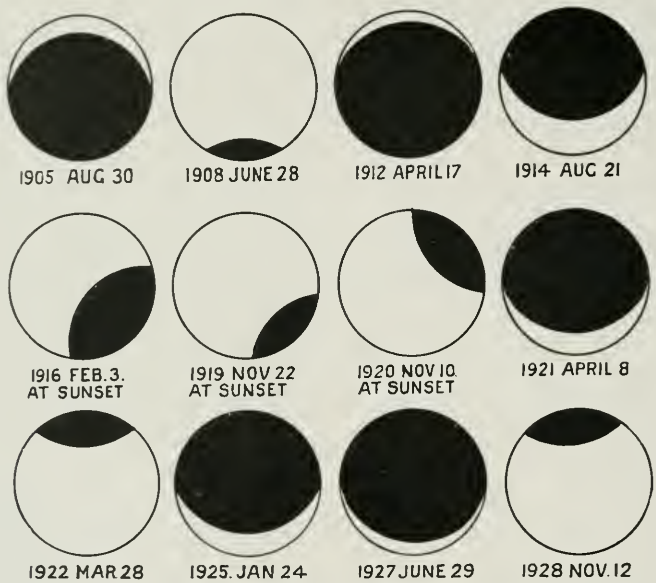


FIG. 6.—SOLAR ECLIPSES VISIBLE IN ENGLAND FROM 1905 TO 1928 INCLUSIVE.

* Compiled from a table of future eclipses by the Rev. S. J. Johnson in his work on "Eclipses, Past and Future," pp. 92–93.

2026 (August 12th), 2075 (July 13th), 2081 (September 3rd), 2090 (September 23rd), and 2093 (July 23rd). In the twenty-second century there will be four great eclipses, as follows: 2135 (October 7th), 2142 (May 24th), 2151 (June 14th), and 2200 (April 14th).

Not a single eclipse of the sun (total) visible at Greenwich may be expected to occur during the next 600 years—a fact which in itself sufficiently proves the great rarity of such a spectacle at any given point of the earth's surface.

The last two eclipses total in England occurred nearly together—viz. on May 2nd, 1715, and May 22nd, 1724, with an interval of nine years, or half a Chaldæan period. Indeed, it not unfrequently happens that large solar eclipses succeed each other at this interval; for example we may refer to those of January, 1880, 1889, and 1898. According to Halley, no total eclipse was observed at London between March 20th, 1140, and May 2nd, 1715.

The curious eclipse represented in Fig. 7 was observed and depicted by Feilitzsch on July 18th, 1860. Some remarkable streamers and flames were seen emanating from the sun during the period of totality. The figure shows the blackness of the moon as compared with the sky on which the corona was projected.

Total eclipses of the sun are necessarily of very brief duration, never exceeding a few minutes. This will be evident on a consideration of the elements involved. The maximum apparent diameter of the moon being 2,011″, and the minimum apparent diameter of the sun being 1,892″, there is a difference in size of only 119″ under the most favourable circumstances of totality; and when it is remembered that the moon's synodic velocity carries her over 30″ in a minute of time, we shall understand at once how the transient character of these total eclipses are to be accounted for. We can also perhaps appreciate the anxious feelings of observers of such a phenomenon who may have travelled many hundreds of miles to note the important details manifested during the short interval. Every moment must be utilised in recording the impressive and varied stages of its progress. The effects upon surrounding objects are startling. The observer, withdrawing his eye from the telescope and looking round, sees an

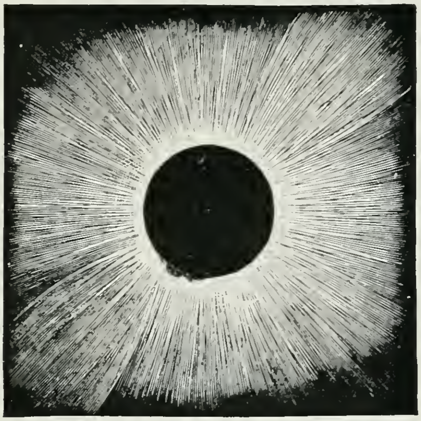


FIG. 7.—THE ECLIPSE OF 1860 (FEILITZSCH).

unnatural gloom settled on the landscape, the faces of persons standing near have assumed a death-like aspect, the planets and brighter stars have come out; and, indeed, the spectral, shadowy nature of the unique spectacle before him is such that, while defying felicitous description, it makes an impression which can never be effaced from the memory.

The visibility of certain bright stars during the short period of totality has suggested that, should a new planet exist between Mercury and the sun, the occasion would be extremely favourable for its detection. At other times it would be invisible, from its constant proximity to the sun, and would obviously not be perceptible as a morning or evening star, for at greatest elongation it would never depart more than a few degrees from his

side. Observers of total eclipses have therefore kept these facts before them, and in some instances special efforts have been made to discover any unknown orb should it exist in the circum-solar regions. Hitherto, however, the quest has proved fruitless, though several dubious objects have been detected from time to time, and have given rise to animated discussion, without, however, any definite result being arrived at in affirming the reality of the supposed new orb. Investigations made in recent years have, in fact, rather furnished a negative, and astronomers have now ceased to regard it as probable that an unknown planet revolves in the space separating Mercury from the sun.

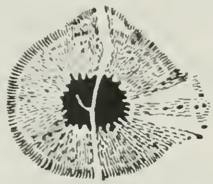


FIG. 8.—SUN SPOT OF APRIL 6TH, 1903.

It is often an interesting feature of solar eclipses to watch the moon's dark limb encroaching upon the sun-spots, and to note their successive reappearances. These solar spots are sometimes very numerous and varied, and a large specimen is occasionally visible, as in April, 1903 (Fig. 8).

The intense glare of the sun renders it necessary in observations of solar eclipses to protect the eye with tinted or smoked glass. The phenomenon is then conveniently witnessed during its various stages, and if a telescope provided with such a glass is at hand the interesting features of the occurrence will be fully brought out. Occasionally, when the eclipse happens with the sun at a low altitude, there is sufficient mist to moderate his intense lustre to a suitable degree, and the progress of the phenomenon is watched with great facility. This happened before sunset on October 8th, 1866, when the sun became immersed in a band of fog lying over the western horizon, and the eclipse then taking place afforded a striking spectacle to many observers.

The ancients connected eclipses with the chief contemporary events of history. Ricciolus has, indeed, given a list of eclipses, with their historical relations. Among them we find the following: B.C. 585 (May 28th), an eclipse of the sun, foretold by Thales, by which a peace was brought about between the Medes and the Lydians; B.C. 431 (August 3rd), total eclipse of the sun—a comet and plague at Athens; B.C. 168 (June 21st), a total eclipse of the moon—the next day Perseus, King of Macedonia, was conquered by Paulus Emilius; A.D. 306 (July 27th), an eclipse of the sun—the stars were seen, and the Emperor Constantius died; A.D. 1133 (August 2nd), a terrible eclipse of the sun—the stars were seen; a schism in the Church occasioned by there being three Popes at once. But the earliest eclipse of which a good record is preserved occurred on June 15th, in the year 763 before the Christian era, at Nineveh, where it was nearly total. An inscription on the Assyrian tablets in the British Museum relates to this phenomenon, which appears to have been a very startling one on account of its great magnitude.

Though a large number of solar eclipses have been sedulously observed by skilled astronomers provided with instruments of the best construction and highest powers attainable, it does not appear that the observational side of the subject is nearly exhausted. The event is not regarded as important simply on account of its spectacular effects. Its value lies chiefly in the circumstance that it can furnish useful evidence on questions affecting the physical character and

changes of the solar orb and his immediate surroundings. The telescope and spectroscope, assisted by the camera, have already effected much in the elucidation of the wonderful phenomena presented, but there still remains an extensive and varied field for investigation. For this reason future total eclipses of the sun will attract the same enthusiastic efforts as those of the past, and observations will be perseveringly continued without any sign of abating interest. The last event of the kind—on May 18, 1901—which offered specially good prospects on account of the long duration of totality, proved somewhat disappointing because of the bad weather which prevailed at several of the best stations. The photographs obtained were not so effective as those secured during the two previous eclipses in 1900 and 1898, and no additional light is likely to be thrown upon questions of solar physics. These issues, somewhat disappointing in themselves, are yet far from discouraging, for ultimate success and failure are necessarily close attendants upon a research of this kind. The phenomena of solar eclipses form a practically endless subject for research, and centuries of further endeavour will greatly widen our knowledge without completing it.

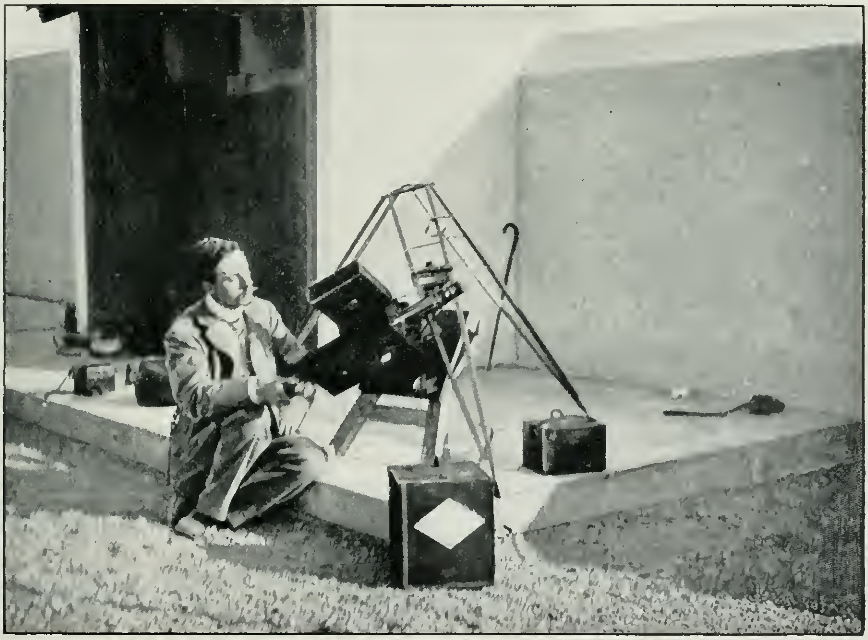


Photo : T. C. Hepworth.

FIG. 9.—PHOTOGRAPHING AN ECLIPSE OF THE SUN IN ALGIERS FOR ANIMATED PICTURES.
The operator is Mr. Cecil Hepworth.

THE TIDES.

FOR the full understanding of the theory of the tides, attainments of a high order are requisite; but the general principles can be understood and appreciated by any person of ordinary common sense. The ebb and flow of the tide, however, together with the daily variation that takes place as regards the time of high and low water, are such familiar phenomena that it will not be necessary here to do more than mention this round of facts that cannot well have escaped the notice of every visitor to the sea shore.

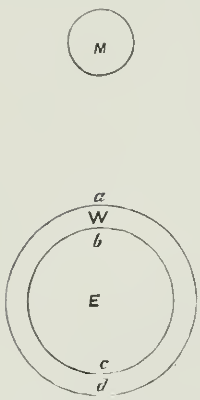


FIG. 1.—THE RELATIONS OF THE MOON, THE EARTH, AND THE SEA.

M, the moon; E, the earth; W, the sea.

Let us at once begin, therefore, by supposing that the earth is a regular globe, with a covering of water of uniform depth all round it (as in Fig. 1); E being the earth, W the water round it, and M the moon above.

Then, as the attraction of gravitation is greater the nearer the bodies are to one another, it follows that the moon will attract the water at *a* with greater energy than it will the earth at *b*; therefore the water will be lifted up, as it were, like what many of us may have seen happen when a body charged with electricity is passed near a person's head—the hair rises up towards the electrified body. Again, the attraction of the moon for the earth at *c* is greater than for the water at *d*, and the result is the earth will be dragged away from the water. From these effects of gravitation, and from the fact of water being a fluid, the water will no longer remain uniform round the globe, but will assume something like the form represented in Fig. 2, being higher at *b* and *c*, and lower at *f* and *g*.

Having thus got a sort of permanent high and low water arrangement, we may next examine the effects of the earth's rotation in twenty-four hours on the relative positions of high and low water. It is quite evident that, as the earth revolves in the direction of the arrow, the point *b* will be brought successively into the places of the points *f*, *c*, *g*, before returning to its original place, and in so doing will pass gradually from high to low water, and from low to high twice in twenty-four hours; and that there will be an interval of twelve hours between one high water and another, supposing the water arrangement remains stationary.

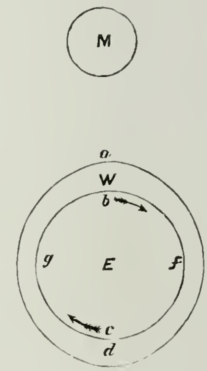


FIG. 2. — HOW THE MOON ATTRACTS THE WATERS OF THE EARTH.

References as in Fig. 1.

We now seem approaching an explanation of the tides; but we still have some work before us, because our observations do not altogether agree with what would be if our explanation were complete. For instance, we observe that the interval between the high water of one day and that of the next is not 24 hours, as it should be by the explanation, but is sometimes as much as $25\frac{1}{2}$ hours. How are we to account for this? In our explanation we supposed the water arrangement in Fig. 2 to remain stationary; but a very little consideration will show us

that this is not exactly correct. It depends, as we have seen, on the influence of the moon, and, of course, if the moon change its place, so also will the water arrangement. As we all know, the moon goes round the earth in about 28 days, and therefore every day it will go a 28th part round the earth. In consequence of this, when point *b* has gone quite round with the earth in 24 hours, and arrived at its starting-point again, the moon will not be right above it as before, but somewhat to the right hand, and will have carried with it the point (*a*) of high water, so before *b* reaches high water again it must travel from *b* to b^2, and this, of course, will occupy a little more time. Fig. 3 will make this clear. The dotted circle marks the moon's original place, and M the new place at the end of 24 hours.

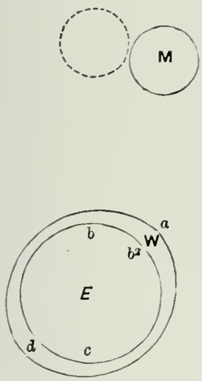


FIG. 3.—THE INTERVAL OF TIME BETWEEN TWO OCCURRENCES OF HIGH WATER IS NOT EXACTLY 24 HOURS.

M, the moon; E, the earth; W, the sea.

This explains very well how high tide should take more than 24 hours to come round again; but it does not explain why that time should vary: why, for instance, it should take $24\frac{1}{2}$ hours at one time, and $25\frac{1}{2}$ at another. Neither does it explain why the point of high water should be lower or higher at one time than another, which we know from our observations to be the case.

Before extending our considerations further, it may here be noted that the points of high water of the two daily tides are not always the same. Let us suppose Fig. 4 to represent, as before, the moon, water, and earth, but revolving in the direction of the arrows, from the top to the bottom of the page, instead of from left to right, as in former figures, then any point *b* in 12 hours would come into the place of b^2, and as the water is symmetrical round the globe, the height of the tide will be the same in both positions. But this would only happen when the moon was directly over the equator or central line marked by the arrows; but it is not always so, it is sometimes on one side and sometimes on the other. Let us suppose it is as in Fig. 5. It is easy to see that, the earth revolving from top to bottom of the page, as we have mentioned, at the point *b*, when, after 12 hours' rotation of the earth, it reaches the point b^2 the tide will not be quite so high.

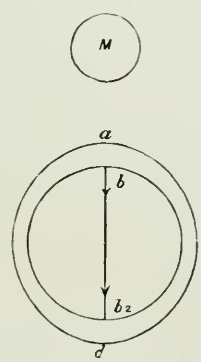


FIG. 4.—THE POINTS OF HIGH WATER OF TWO DAILY TIDES ARE NOT THE SAME.

In 12 hours b has shifted to b^2.

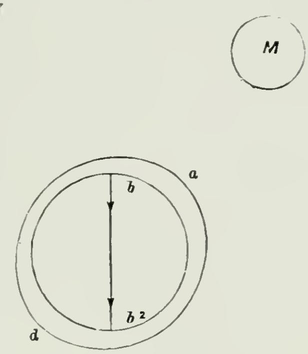


FIG. 5.—TIDES VARY IN HEIGHT.

References as in Fig. 4. The position of M (the moon) is a little exaggerated.

Hitherto we have considered only the action of two bodies in reference to the tides; but there is the sun to be taken into account, and from his great size we would almost imagine that his influence would be more powerful than that of the moon; but it is not so, and the reason is clear enough. Although his size is so great, he is nearly 400 times farther away from the earth than the moon is, and in consequence of this the moon has, roughly speaking, more than twice his power of arranging the water in the tidal form we have shown in our figures. The sun's influence, however, though thus much less than the moon's, cannot be left out of

sight if we are to get a proper explanation of the tides. We have to unite the tides which the sun and the moon would separately produce, and see if the result throws any further light on our observations. All we have said regarding the production of tides by the moon's influence would equally apply to the tides produced by the sun, modified, however, by the fact that the sun takes about 365 days to complete his *apparent* revolution round the earth, instead of 28 days, as the moon does. We shall now proceed to examine the joint action of the sun and moon.

Let us suppose (Fig. 6) that the sun, moon, and earth are in the same straight line: S being the sun, M the moon, and E the earth; *a*, *b*, *c*, *d*, *f*, and *g* denoting the same points as before. In this case we shall have the tides due to the sun and moon superposed, and we shall have very high water at *b* and *c*, and very low water at *f* and *g*. As we have seen, the moon moves more quickly in its course round the earth than the sun, consequently will rapidly leave the straight line joining the earth and the sun. In doing this it will carry with it its share of the high tide, and when it completes its first quarter the two tides due to the sun and the moon will be at right angles to one another, and, instead of being superposed, they will partially neutralise each other.

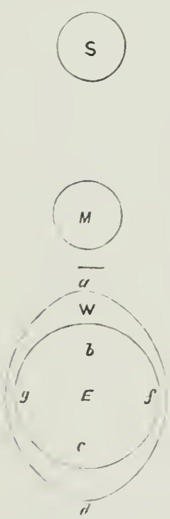


FIG. 6.—THE SUN AND THE MOON ACTING IN CONCERT PRODUCE VERY HIGH TIDES.

The highest or "spring" tide is thus brought about.

The result is some such arrangement of the water as in Fig. 7, which approaches the form of a circle much more than Fig. 6. As the moon, however, has twice the tide-producing power of the sun, the crest of the tidal wave will still be nearly under it, as at *a*, so that there will be high water on the earth at *f* and *g*, and low water at *b* and *c*; but the high water will not be nearly so high, nor the low water so low, as in Fig. 6, when the sun and moon are in a straight line with the earth. In fact,

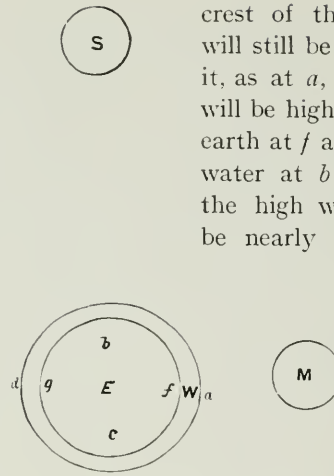


FIG. 7.—HOW "NEAP" TIDES ARE CAUSED.

Here the sun pulls against the moon, but, although the moon is the stronger, the result is a very low or "neap" tide.

Fig. 6 represents what is usually called "spring tide," and Fig. 7 "neap tide"; the former being the highest and the latter the lowest semi-monthly tide. These phenomena will be repeated in an inverse order as the moon moves on in its course. When the moon arrives at the opposite side of the earth from the sun, but on the same straight line, or at "full moon," there will be "spring tide" again at *b* and *c*, and when the moon reaches its third quarter there will be "neap tide" at *f* and *g*. Thus there are two spring tides and two neap tides every revolution of the moon round the earth. This agrees with our observations, and gives us a reason for the varying heights to which high water rises—viz. the varying positions of the sun and moon relative to the earth.

We have now to explain the reason why the interval between the high tide of one day and the high tide of the next should vary; why it should sometimes be $24\frac{1}{2}$ hours, and sometimes more, till it reaches $25\frac{1}{2}$ hours. If we turn to Figs. 6 and 7, and consider the action of the sun and moon on the water, we see as the moon moves away from its position in

Fig. 7 it drags the crest of the tidal wave away with it; but the sun also tends to keep the crest of the wave back towards the point *b*. The result of these antagonistic actions is that the tidal wave is kept back or retarded behind the moon somewhat, till it passes its first quarter. After it passes that position, the action of the sun tends to carry the crest of the wave towards the point *c*, and this tends to hurry on or accelerate the progress of the tidal wave, more than the moon's action alone would do, until it is full moon. This process is repeated as the moon passes to its third quarter, and then to new moon. This gradual retardation and acceleration gives a pendulum-like swing to the tides. If we imagine the crest of the wave to be the bob of the pendulum, it rushes from its slowest point with gradually increasing velocity till it reaches its fastest, then gradually gets slower again, and makes, as it were, two swings in the time the moon takes to go round the earth. This motion quite explains the variations in time of the tides; for when the wave is travelling slowest the point *b* in Fig. 3 comes more quickly up to the crest of the wave than it does when the wave is travelling at its fastest rate.

We have thus pointed out in a general way an explanation of the various phenomena we notice in the ebb and flow of the tides, and conclude that they are due mainly to the joint action of the sun, moon, and earth, as they change their relative positions in their various rotations. Of course, we have imagined the earth to be perfectly globular, and the water uniformly distributed round it, and as neither of these conditions obtain in the actual earth and ocean, we shall find many things modifying our conclusions: but in the main we shall find them accurate.

Now, apart from the mere movement of the oceanic waters, there are other matters which on a brief consideration may, perhaps, be found of interest. Thus there are certain circumstances that arise as regards the water and the atmosphere, which is everywhere in the closest intimacy with it. The varying force of the wind, for instance, has a pronounced influence on the movements of the sea, and in estimating the height to which the tide will rise in any given locality the variations in the direction and velocity of the wind are factors that need always to be taken into account. In order to illustrate this modifying influence, it is only necessary to direct the attention to what occurs in certain rivers, such, for instance, as the Hooghly, and in a less degree in rivers like the Thames, to show what may be done as regards producing unexpectedly high tides when the wind happens to blow in a certain direction. Gales, when they blow in the same direction as the main stream of the flood-tide, cause an elevation of the crest of the tidal wave along the coast, the reverse taking place when the wind is opposed to the flood-tide. The difference in the height of the tide from such a cause is often as much as three or four feet.

But not only does the wind increase and restrain the daily oscillations of the tide, but other modifications are introduced by the mere weight of the air that is pressing on the surface of the water. The pressure of the atmosphere, as shown by the barometer, is constantly changing, and the ocean is able to rise higher when the pressure is decreased, its movements being restrained when the pressure is increased. The ocean, indeed, readily pulsates in response to the movements of the air pressing on it, and in this respect is like the mercury in the cistern of a barometer, where the pulsations are, of course, more readily recognised. This pulsation of the ocean has been a subject of investigation, and it would appear that a fall of an inch in the barometer may make a difference of nearly a foot in the

height of the tide. From a practical point of view, therefore, the wind and the variations in atmospheric pressure are important modifying causes to be allowed for when calculating the height of the tide in any given locality.

These variations are, of course, best shown by the records obtained by tide-gauges (Figs. 9 and 10). These instruments consist primarily of a float that rises and falls with the tide. To this float is attached a cord that passes over a pulley, and pulls up or down a pencil or pen attached to it. By this means a mark may be made on a strip of paper that is wrapped round a cylinder that is revolved by clockwork. Such an instrument as this gives a continuous record of the variations in the height of the tide at every minute throughout the day, and affords an interesting record with which the changes in the wind and atmospheric pressure may most readily be compared. It was instruments such as these that revealed the tidal wave that went two or three times round the world as the result of the volcanic upheaval that occurred in the year 1883 at Krakatoa in the Straits of Sunda, an eruption, it may be said, that was a noteworthy example of the tidal waves that constantly occur as the result of volcanic action.

FIG. 8.—A TIDAL "BORE" ON THE CHINESE COAST.

This is a scene upon the Tsin-Tang river, opposite the city of Hang-Chow. These tidal "bores" frequently do a great deal of damage, and they give little warning of their approach.

The tides also have very marked results as regards the temperature of the air. Water, as is well known, changes its temperature much more slowly than does the land, so that the daily variations are much less in one case than they are in the other. During a sunny day, for instance, the land becomes greatly heated, but at night it quickly parts with this acquired heat, the range in the temperature of the soil being often as many as fifty or sixty degrees. Water, on the other hand, acquires heat very slowly, and is equally reluctant to give up its accumulated stores, so that during the twenty-four hours its variations in temperature do not amount to more than two or three degrees. Now the air that is floating over these two surfaces that differ so widely in their characteristics takes its temperature from the surface with which it is in contact, and it will be understood that some very curious contrasts occur as regards the air over the sea and that over the land. Moreover, the tide, as it advances up certain rivers and estuaries is, as it were, an invading force, and the water naturally brings with it its own peculiar characteristics as regards temperature. At such times it will often happen that warm air from the land flows towards the cooled air floating over the water, and it will, perhaps, be understood that in such circumstances local winds and breezes are produced, all of which are to be set down to the modifying influence of the advancing or receding tide.

Again, at other times the differences in temperature induced by the tide are a fruitful source of fog and mist. Supposing, for instance, the rising water is pushing its way towards a body of warm moist air, the vapour in the atmosphere will condense and appear as a fog or mist. Numerous local fogs and mists are thus developed at places on the coast, and a careful observer will in many instances have no difficulty in tracing them to the direct action of the incoming tide. This same difference as regards temperature may at times even precipitate local rain showers. But enough has probably been said to show that there is a close relationship between the tide and numerous changes that may be noticed as regards the atmosphere.

A further noteworthy point is that the rise and fall of the tide are a powerful means of altering the pressure on the crust of the earth. It is not always realised how enormous this pressure really is. A fall of one foot in the tide, however, means that 80,000 tons have been lifted off every square mile of the ground above which the water is circulating. Bearing these figures in mind, a little consideration will suggest tremendous possibilities. Now, one of the most noteworthy results that follow the removal of this great load of water has reference to the production of earthquakes. At such times the underground gases very often find an oppor-

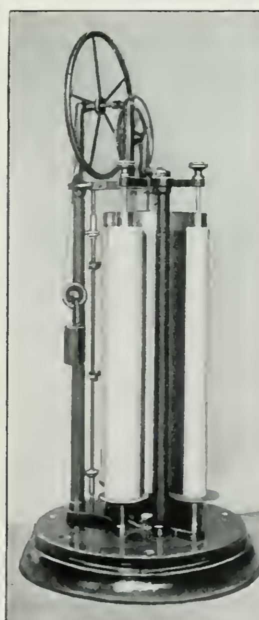


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FIG. 9.—WATER-LEVEL AND PORTABLE TIDE-GAUGE FOR HARBOURS.

tunity to escape, and the vacancy thus created is promptly filled by the sea-water. When such water encounters the molten lava, or some other form of underground heat, vast stores of steam are evolved, which develop an expansive force that results in an earthquake or volcanic eruption. It was in this way that the Lisbon earthquake was caused, and other instances might be quoted as illustrating the destructive forces that sometimes spring into being as a result of a fall in the height of the tide.

There is one more fact connected with the tide which has attracted considerable attention of late years, and which is worthy of our consideration for its far-reaching consequences. As we have endeavoured to show, the tides are caused mainly by the moon, as it were, catching hold of the water as the earth revolves round on its axis. This must cause friction on the earth as it revolves, and friction, as everyone knows, causes loss of power. Suppose a wheel with hair round its brim, like a circular brush such as is used for hair-brushing by machinery; if this brush be revolving rapidly, and we hold our hand ever so lightly on the hair, so that it is slightly rubbed backwards as the wheel revolves, we can understand that the speed of the wheel will be gradually diminished, until at last it will be brought to a standstill, provided there is no additional power communicated to the wheel by machinery or hand beyond what was given to set it spinning round. Now this is somewhat analogous to what is happening to the earth in its rotation. There is reason to suppose that the action of the tides is slowly but surely lessening the speed of the earth's rotation, and consequently increasing the length of the day, and that this action will continue until the earth revolves on its own axis in the same time that the moon takes to revolve round the earth. Then the day, instead of being twenty-four hours as now, will be about twenty-eight days, and the earth will be exposed to the full blaze of the sun for about fourteen days at a time. The change this will bring about on the face of the earth can hardly be exaggerated. All life, both animal and vegetable, will be destroyed; all water will be evaporated; the solid rocks will be scorched and cracked, and the whole world reduced to a dreary and barren wilderness. It is supposed by some that the moon has already passed through all this, which explains its shattered and bare-looking surface. The earth being so much larger has more quickly acted upon the oceans which once were upon the moon's surface, and stopped almost entirely its revolution round its own axis, thus causing it to have a day equal to twenty-eight of our days, and the heat of the sun has already

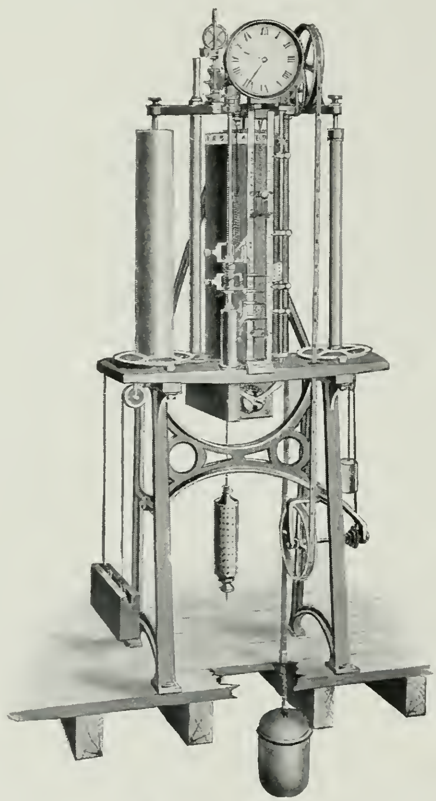


FIG. 10.—A COMBINED TIDE AND WIND GAUGE.
(By permission of Messrs. A. Légé & Co.)

done to it what in future ages it will do to the earth.

We may, then, with perfect propriety, regard the tides as a gigantic brake which is slowly but surely reducing the rotation of our planet, until at last we come to rest with one side opposite to the sun, a world as dead as the moon probably is to-day.

FIG. 11.—A TIDAL WAVE AT MOUNT'S BAY, CORNWALL.

Tidal bores or waves are not unknown on our own shores, although they are never of such magnitude as those upon the Chinese coasts. In this case the "wave" upset the arrangements of a Dutch auction which was being held upon the sands.

THE MATHEMATICS OF PLANTS.

THE great variety in the external aspect or habit of plants has relation to several conditions, such as the character of the stem as regards height, and branching; the size, form, colour, and covering of leaves, and their arrangement on the stem. In the latter respect there is generally clear evidence of definite order. The ordinary observer may find a little difficulty at first in examining the subject, but some knowledge of it will add materially to the pleasure derived from the cultivation and examination of plants. We shall find that there is order in what looks, at first sight, confusion, and that even the leaves of a plant are not attached to the stem without obeying certain fixed, though simple, mathematical laws. It is necessary at the outset to explain a few technical terms used by botanists. The part of the stem or axis to which a leaf is attached, or from which it springs, is called a *node*; the space or part of the axis between one node and the other, above or below, is called an *internode*, and these spaces are longer or shorter in different plants. It will be found as we proceed that the size and form of the leaves, the length of their petioles, the length of the internodes of the stem, and the arrangement of the leaves on any particular part of the plant, have all a definite bearing or relation to one another. The relative positions of leaves on the axis, or the way in which they are distributed on the stem, is technically called *phyllotaxis*, or *phyllotaxy*—from two Greek words which signify *leaf* and *order*, or *arrangement*. The most common arrangement is the *alternate*, or spiral (Fig. 1), in which the leaves stand singly on the nodes. Some common plants are instances, as the poplar, the oak, and the apple; in other cases, a node appears to support two leaves—one on one side, another on the other side of the axis. The term *opposite*, or cyclical, is applied to such cases (Fig. 2).

FIG. 1.—THE LEAVES OF THE ALDER ARE ARRANGED UPON THE "ALTERNATE" PLAN.

The point from which the leaf springs is termed a "node." The space between two nodes is technically known as an "internode."

Two of our native orchids—such as the twayblade (*Listera*), not uncommon in shady meadows and woods—may be mentioned as examples.

It is, however, worthy of notice that usually the pairs of opposite leaves alternate with each other, forming a cross—that is to say, if we place the stem before us, and observe a pair of leaves one on the right, the other on the left, the next pair will stand one in front and the other behind; the successive pairs of leaves are then described as *decussate* (Fig. 3). Taking a glance at any one pair of leaves, it will be observed that they are inserted on the stem at a distance from one another of just half the circumference of

the stem (a circle is 360°), and they are thus separated from one another by 180°. This is termed the *angular divergence*. The next pair above is at a right angle (90°) from the first, while the third pair is exactly above the first, and may be regarded as the beginning of another set or series. Thus we have two pairs completing what might be termed a story, each story being succeeded by other stories on exactly the same plan. As each pair forms a cycle, and two cycles constitute a story, the phyllotaxy of such a plant is indicated by $\frac{1}{2}$. Familiar examples of this plan of arrangement may be found in the dead nettles, and other members of the Labiate order, pink, honeysuckle, and elder.

According to the size of the leaves and the length of their petioles, so will the internodes of the stem be proportioned, in order that every leaf may have its due share of the sunlight. The larger the leaves on upright stems, the longer

FIG. 2.—THE "OPPOSITE" ARRANGEMENT AS SEEN IN ST. JOHN'S WORT *(Hypericum calycinum)*.

will their petioles be; or if the stalks are short or entirely wanting, the internodes of the stem will be duly elongated. The *decussate* plan of arrangement is most obvious on upright stems or branches; but when these assume an arching or

FIG. 3.—WHEN SUCCESSIVE PAIRS OF LEAVES CROSS THEY ARE SAID TO BE "DECUSSATE," AS IN UPRIGHT STEMS OF ST. JOHN'S WORT.

drooping position, as in St. John's wort (Fig. 2), either the internodes, the petioles, or both, twist so that the blades of the leaves arrange themselves in one plane, apparently in two rows, one on each side of the stem. In like manner the procumbent stems of the wild thyme are clothed with leaves that, by the twisting of their petioles, face the zenith. The leaves of upright stems of the large-flowered rock rose (*Helianthemum grandiflorum*) are opposite and decussate, but those on procumbent stems form two spreading ranks, with some of the leaves forming a third row at right angles to and down the middle line between the other two ranks. At the apex of the upright shoots of the maple we find a rosette of leaves. On drooping branches the leaf on the lower side is larger than the other member of the pair. Precisely similar arrangements are met with in the horse chestnut (*Æsculus*).

Take, again, the common bed-straw

(*Galium*), or madder, and we find the leaves arranged after what is known as the *verticillate*, or whorled manner. Here we find that more than two leaves appear to come from the same node. In these cases also we find alternation of leaves in the successive whorls—that is, each leaf usually stands opposite the spaces between the leaves of the next whorl. Some of these so-called leaves, however, are *stipules*,* and may be traced in the seedlings of *Galium Aparine* and *G. saccharatum*. In the British water milfoil (*Myriophyllum verticillatum*) there are five leaves in a whorl ($\frac{1}{5}$), and the next whorl alternates, making ten leaves in a story, so that there are ten vertical rows on the stem.

FIG. 4.—VERY COMPLICATED: THE $\frac{5}{13}$ SYSTEM.

The spiral arrangement of leaves is much more common than the opposite or whorled, and will be found to afford much greater facilities for the proper disposition of the leaves with regard to light in the multifarious forms of plants constituting the vegetation of the globe.

If, in the case of alternate leaves—like those of the elm or lime tree—we suppose a line drawn round the stem and touching the point of attachment of each leaf, it will be seen to be a spiral line; or fasten one end of a thread to the stalk of a leaf low down on the stem, then carry it to the next leaf above and give it a twist or turn round the base of it, and so on; the nature of the line of connection can then be seen: there is, in fact, a *helix* which, in passing round the stem, is more or less regular.

Strong-growing and upright branches of the alders, hazels, and beeches differ from the spreading or drooping ones in having a $\frac{1}{3}$ phyllotaxy, the angular divergence of the leaves being 120°. There are three leaves in a story, and the fourth leaf, being vertical to the first, commences another cycle or story. The three leaves make one circuit or helix of the stem. Beginning at any leaf, it will be found that the first leaf of the second story is perpendicular to it, the second leaf of the first in line with the second leaf, and the third with the third one of the second story. The $\frac{1}{3}$ arrangement also occurs in sedges (*Carex*).

In many plants—such as the apple, peach, cherry, and poplar—the leaves present a five-ranked arrangement. Beginning with one leaf, two circuits round the stem are necessary before reaching the leaf directly above the one from which the series began. The fraction $\frac{2}{5}$ is used to indicate this—that is to say, two turns round the stem, and the sixth leaf directly above the first; therefore 5 leaves in the cycle. Figs. 5 and 6 show a spiral and horizontal projection of a $\frac{2}{5}$ arrangement.

In the $\frac{1}{2}$ and $\frac{1}{3}$ plans of phyllotaxy we found that one circuit of the stem constituted a story, but in the $\frac{2}{5}$ plan it

* A "stipule" is a little appendage usually springing from the base of the "petiole" or leaf stalk.

requires two circuits to complete the spiral or story, so that the angle of divergence from one leaf to another, up or down the stem, from the point of commencement is 144°; and as a story includes five leaves it follows that there are five perpendicular rows of leaves. Other instances of the $\frac{2}{5}$ phyllotaxy are met with in oaks, willows, pæonies and poppies.

In some trees and shrubs the $\frac{1}{2}$ and $\frac{2}{5}$ forms of phyllotaxy are interchangeable when circumstances demand it. There are frequent instances of it in the rose family, two well-known examples being the Portugal laurel (*Prunus lusitanica*) and the laurel-cherry (*P. Laurocerasus*).

When we make three turns round the

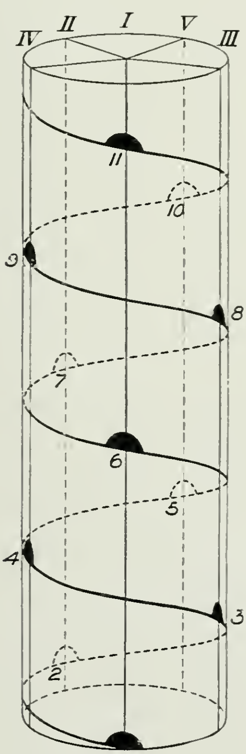


FIG. 5.—SPIRAL PROJECTION OF $\frac{2}{5}$ ARRANGEMENT: VERTICAL.

The figures show the successive leaves, and the Roman numerals indicate the exact point upon the circumference of the stem at which they originate.

stem before reaching a leaf right above the first, the expression is $\frac{3}{8}$, 3 being the number of turns, and 8 the number of leaves in the cycle or story. The angular divergence in this case is 135°; and as there are eight leaves in a story it follows

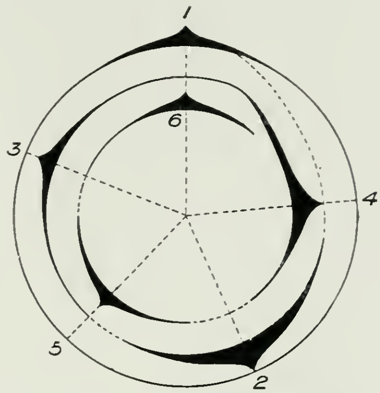


FIG. 6.—SPIRAL PROJECTION OF $\frac{2}{5}$ ARRANGEMENT: HORIZONTAL.

that there are eight ranks of leaves on the axis, each rank separated from the other by $\frac{1}{8}$ of the circumference of the stem. This plan is found in many species of holly. The leaves of plantains are in dense rosettes. Those of *Plantago media* closely hug the ground, and, though there are relatively few in a rosette, with a phyllotaxy of $\frac{3}{8}$, cases occur with thirteen leaves in a story The complete spiral passes round the axis five times, being represented by $\frac{5}{13}$. The scales on the cone of the Weymouth pine (*Pinus Strobus*) is an instance.

There are other arrangements, and all may be set down here—$\frac{1}{2}$, $\frac{1}{3}$, $\frac{2}{5}$, $\frac{3}{8}$, $\frac{5}{13}$, $\frac{8}{21}$, $\frac{13}{34}$, $\frac{21}{55}$, etc.

Now, on examining these expressions, an interesting result comes out—a fraction has its numerator equal to the sum of the numerators of the two preceding, and the same is true of the denominator. One example may suffice. Taking the two first—$\frac{1}{2}$, $\frac{1}{3}$—these by addition give the next, $\frac{2}{5}$. Thus,

$$\frac{1}{2} + \frac{1}{3} = \frac{1 + 1}{2 + 3} = \frac{2}{5}$$

The more simple arrangements are of frequent occurrence; where the internodes are very short, the leaves are crowded,

and the analysis of such cases is more difficult, as in the rosettes presented by the leaves of *Plantago media.* The same difficulty occurs with some *Sedums* or stonecrops, and *Sempervivum* or houseleek (Fig. 7, $\frac{5}{13}$ arrangement), and the cones of firs. Nevertheless, the general spiral arrangements are in such cases obvious enough; instead of one simple spiral there are several parallel or secondary spirals, more or less numerous. This is best seen in any large, or even small, fir-cone. Some of the spirals run from left to right, others the reverse. In such cases the primary or generating spiral has reference to a full series of the leaves on the axis, the spiral line passing through every leaf: the secondary spirals are only partial—that is, do not embrace every leaf or scale. In such cases, the fundamental spiral cannot be easily followed; but an examination of the secondary spirals will give assistance in this. These secondary spirals vary in number according as the fractional sign of the primary spiral is higher.

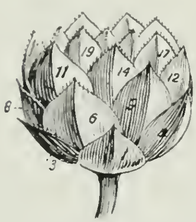


FIG 7.—THE LEAVES OF THE HOUSELEEK.

Here the internodes are very short, the leaves are crowded and a rosette is formed.

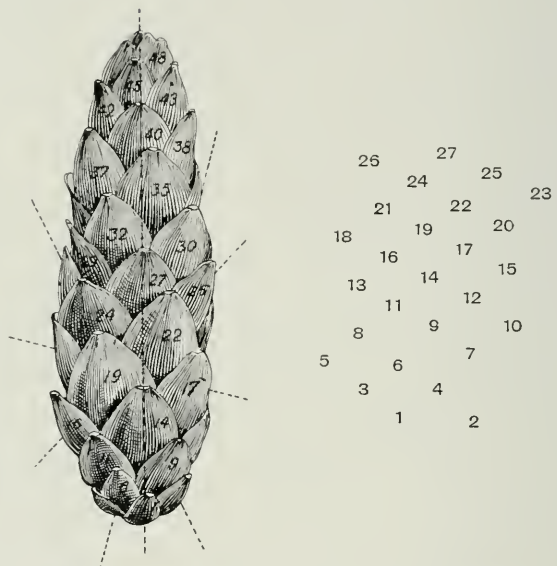


FIG. 8.—CONE OF THE WEYMOUTH PINE WITH SCALES NUMBERED AND A PROJECTION OF THE ARRANGEMENT.

The cone of *Pinus Strobus*—white or Weymouth pine—is frequently used to illustrate this subject, and the same example may be adopted here. Fig. 8 represents one side of the cone with the scales numbered, and beside it a projection of the arrangement $\frac{5}{13}$, the normal in this cone, the number 14 being directly above the scale number 1, the cycle consisting of 13 scales, the spirals being 5. A line which passes to the left through the numbers 1, 2, 3, 4, etc., makes five turns round the cone before it ends at 14, directly above 1. There are 5 parallel spirals of the order 1, 6, 11, etc. (these give the numerator), and 8 of the order 1, 9, 17, etc.; then 8 and 5 give 13, so that the primary spiral expressed by $\frac{5}{13}$ may be got from the number of secondary spirals parallel to one another.

Although the angular divergences of leaves represented by the series of fractions already given are, on the whole, fairly constant in individual plants, still it must be noted that there are deviations. Starting from one leaf, and following up the spiral, we may find a leaf vertically over

the first, which will give a fraction different from the ordinary one.* Most fir-cones have such arrangements as are expressed by the ordinary terms, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{2}{5}$, $\frac{3}{8}$, $\frac{5}{13}$, etc., whose generating and successive secondary spirals are shown by the numbers 1, 2, 3, 5, 8, 13, etc.; but cases occur in which there are either conjugate spirals of the ordinary system, or there are arrangements which may be referred to other systems.

Bravais and others have explained some of these abnormal arrangements by supposing partial abortion of one of the spirals, or coalescence of two secondary spirals into one. Professor Dickson's objection to this idea is that secondary spirals are only relative, and he shows that in some cases there is coalescence or union of two consecutive scales of the secondary spirals, giving rise to disturbance, this being really the true explanation. In other cases, it is considered that the ordinary simple spiral and the ordinary bijugate are fundamental forms—that is, forms with either of which a cone may commence without the intervention of another. The derivations of the different systems from the one or from the other would thus be a simple matter.

Variations of the angular divergences of the leaves of the Jerusalem artichoke (*Helianthus tuberosus*) have been examined by the Rev. George Henslow.† He observed transitions from one kind of divergence to another: $\frac{2}{7}$, $\frac{3}{11}$, were not uncommon, and more rarely an approach to $\frac{1}{4}$ and $\frac{5}{18}$. But these can be arranged in a series analogous to the usual one—viz. $\frac{1}{4}$, $\frac{2}{7}$, $\frac{3}{11}$, $\frac{5}{18}$, etc.—that is to say, numerators being the same, the denominators of the successive fractions of the secondary series are equal to the sums of the numerators and denominators of the corresponding fractions of the ordinary or primary series. Mr. Henslow shows that any one series can pass into another if it be represented by a generating spiral, the angular divergence of which is a low one in that series. In the same paper a comparative view is given of fractions belonging to deviations from the ordinary or primary series, thus:—

Primary series, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{2}{5}$, $\frac{3}{8}$, $\frac{5}{13}$, $\frac{8}{21}$, $\frac{13}{34}$.
Secondary series, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{2}{7}$, $\frac{3}{11}$, $\frac{5}{18}$, $\frac{8}{29}$, $\frac{13}{47}$
Tertiary series, $\frac{1}{4}$, $\frac{1}{5}$, $\frac{2}{9}$, $\frac{3}{14}$, $\frac{5}{23}$, $\frac{8}{37}$, $\frac{13}{60}$.

Here the sum of the denominator and numerator of the third fraction of the primary series gives the denominator 7 to the third fraction of the secondary series, and so on; and, as in the primary series, so in the others, the sum of the denominators of two adjacent fractions gives the denominator of the next succeeding.

It has been already stated that in the primary series any numerator is the same number as the denominator of the fraction next but one preceding. This relation does not hold in the others; "but if it be remembered that the denominators can be formed by adding the numerator and denominator of the corresponding fraction of the preceding series the true and general relation at once appears." The following are examples:—The denominator of the fraction $\frac{3}{8}$ supplies the numerator to the fraction $\frac{8}{21}$; but in the secondary series the denominator is 11 (*i.e.* 8 + 3); so also in the tertiary series the denominator of the corresponding fraction is 14—that is, 11 + 3 is equal to 8 + 3 + 3. The fourth fractions may, therefore, stand thus:

$$\frac{3}{8},\ \frac{3}{8+3},\ \frac{3}{8+3+3},\ \frac{3}{8+3+3+3},\ \text{etc.}$$

Mr. Henslow shows by a diagram (Fig. 9) that "the angular distances included by the limiting positions of the second leaves of all generating spirals, commencing at 0, decrease according as the spirals belong to the secondary, tertiary, or quaternary series; so also does the

* As has been shown in the case of some firs by Professor A. Dickson. ("Transactions" of the Royal Society, Edinburgh, Vol. XXVI.)

† "Transactions" of the Linnean Society, Vol. XXVI.

number of leaves in a single coil increase correspondingly: and, therefore, the higher the series, the more nearly does any spiral belonging to it approach the verticillate condition, provided the internodes be but slightly developed."

It may be stated here that in some of the lower forms of plants, such as mosses and ferns, the angle of divergence of the leaf-organ is related to the principle of growth. In the $\frac{1}{2}$ arrangement the cell at the end of the axis is divided into two. When the segmentation or division of the apical cell is in three rows, each new division-wall of the cell at the apex being parallel to the last division-wall but two, two rows of leaves are formed, arranged spirally with the divergence $\frac{1}{3}$. The segmentation, then, of the apical cell has a relation to the leaf-arrangement in Cryptogams—mosses, etc.; in Phanerogams—flowering plants—the same relation does not hold.

It may not be out of place to refer here to attempts having reference to approximate measurements of the mean curves of leaves. The subject has been examined by Mr. W. Mitcheil.* Taking an outline of a leaf, he selects a point $\frac{1}{4}$ of the midrib from the base, and from that he draws *radii vectores* to the outline, corresponding to equal arcs, into which a circle described round the pole or point is divided. On each side of these primary radii others are drawn at equal distances, and each is measured by a scale of equal parts. The length of each principal radius, added to that of each of the secondary, and the sum divided by the total number, gives a mean radius to each primary division of the circle. It is conjectured that a series of careful measurements made in this way would afford data for comparing the average variation in form of the leaves of any plant, which might lead to numerical relations throwing light on the laws of vegetable morphology. In his second paper Mr. Mitchell treats of equations to the curved outlines of the leaves of plants. He proposes to find formulas to express the curves of the outlines of leaves, so that the calculated values should not differ from the measured, more than the proportional measurements of several leaves of the same plant differ among themselves, by reason of their ordinary variations.

He traces the outline of a well-developed

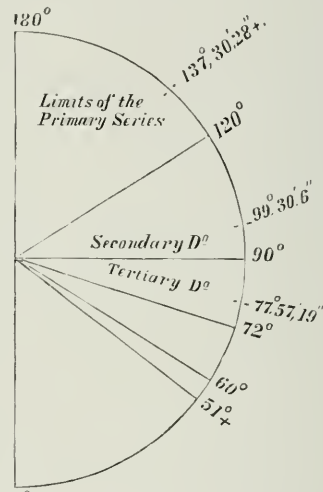


FIG. 9.—DIAGRAM ILLUSTRATING MR. HENSLOW'S THEORY.

leaf on paper. The base of the mid-rib is taken as the origin of measurement, and from it lines are drawn to the margin, making equal angles with each other. These being measured by a scale divided into tenths of an inch, and the first line or radius vector being longest, we have a descending series of terms from which to construct a formula for the curve in question, in simple, undivided leaves. Little modification is necessary to the more regularly divided leaves, and to compound leaves. In the five-lobed leaf of maple the radiating vein of each lobe may be compared to the mid-rib of a single leaf, and a formula found for 3 out of the 5. The intersections of the

* "Transactions" of the Edinburgh Botanical Society, Vols. VI. and X.

curves will produce the outline of the simple divided leaf, when set off on 5 axes, making usually an angle of 45° with each other.

In the simple leaf of laurustinus, the

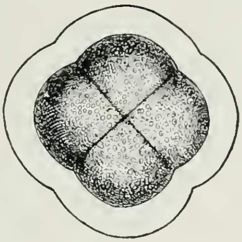


FIG. 10.—PERSISTENT POLLEN.

The divisions between the four grains are already apparent. For further development see Fig. 11.

radii for angles of 10° are 34, 26·2, 20, 15, 11, 7·23, 5, 2·6, 0·2, 0, being nearly the same results as by actual measurement—viz. 34, 26, 20, 15, 11, 7, 5, ·2, 0.

Attention may now be directed to the number 4, or a multiple of it in some of the lower forms of plants. The instances are so numerous that a few examples may suffice. It is also worthy of notice that division of protoplasm into two is not uncommon. This is well illustrated in the development of the reproductive *spores*, as they are called.

The gills of mushrooms are covered with numerous club-shaped cells—*sporo-*

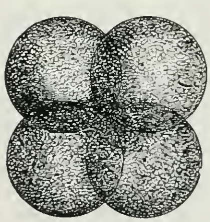


FIG. 11.—PERSISTENT POLLEN.

The four grains are now fully developed, but they cannot decide to dissolve partnership.

phores or spore-bearers—on the summit of which the spores are in groups of 4. In others, such as the well-known mushroom called the morel, there are eight spores in an oblong case or cell. In one of our most common sea-weeds, *Fucus vesiculosus*, or bladder fucus, so called from numerous air-vesicles on it, the contents of the *oogonium* divide into eight portions.

The spores or seed-like organs of mosses are produced in fours. In the common male fern, *Aspidium Filix-mas*, they follow the same law.

This is also illustrated in the development of the grains of the dust-like pollen, which is shaken out of the flowers of the higher plants, or those which have obvious flowers. This is well seen in the earlier stages of the pollen in mallow. After the four very young grains escape from the mother-cell and are free, they increase in size, and the surface becomes rough with projecting points. In some cases the grains, after escaping from the parent cell, even when mature, remain bound together, thus giving composite pollen.

FIG. 12.—TEETH OF *TETRAPHIS*.

This moss has many teeth to the "peristome," but the number is always four or some multiple of that number.

This occurs in species of *Typha* (cat's-tail) or bulrush. An early stage of the pollen remains persistent (Figs. 10 and 11).

We may finally bring under notice the very notable law which prevails in the number of the teeth which surround the mouth of the ripe capsules or cases which contain the spores of mosses. It may be stated, in passing, that these teeth, forming what is called the *peristome*, are highly sensitive to moisture, folding over the mouth of the capsule, or unfolding outwards, according to the state

of the atmosphere as regards moisture or dryness.

The numbers of these teeth, when present, are 4, or some power of 4 up to 64, being 4 in *Tetraphis* (Fig. 12); 8 apparently in some species of *Orthotrichum* (Fig. 13); 16 in *Grimmia* and others; in *Zygodon*, the outer teeth are considered to be of 32 primary divisions united 2 or 4 together, so as to represent 16 or 8 plain teeth. In *Polytrichum* there are 64 (rarely 32) teeth. Where there are two rows of teeth, which is a frequent character, the law also prevails, and those of the one row alternate with those of the other.

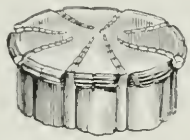


FIG. 13.—THE TEETH OF *ORTHOTRICHUM* (ANOTHER MOSS) ARE NUMBERED IN "EIGHTS."

If we examine the parts of the flower in the higher orders of plants, we observe also that certain numbers prevail, but they are less constant. In those which are called monocotyledonous, in which there is apparently one lobe in the seed, the three-ranked arrangement prevails, as in crocus, iris, tulip, etc. The four- and five-ranked, on the other hand, are most frequent among dicotyledonous plants. Fuchsia, epilobium, etc., have the whorls of the flower in groups of 4. In primroses and pinks the number 5 prevails—that is, the quinary; among them, however, there are some exceptions, the number 3 being seen in magnolia and barberry. As an example of the three-ranked arrangement in the monocotyledonous division we may take the flower of a hyacinth. We observe on the outside 3 parts, or *sepals*, as they are called, forming the *calyx* or cup. More internally, we see other 3—the *petals*—the *corolla*, or coloured part of the flower. Next we find 6 *stamens* in two rows, an outer and inner, and in the centre of the flower a seed-vessel of 3 pieces conjoined; all these alternate with each other. The same succession of parts may be observed in complete flowers of dicotyledons, the numbers in each whorl being, however, mostly 4 or 5, although there are exceptions to this.

It seems to be a fair conclusion, from structures and arrangements here recorded, that in plants, whether high or low in the scale, certain principles regulate the number and arrangement of different organs, and that even in what is popularly considered to be "admirable confusion" the mighty "reign of law" prevails.

FIG. 14.—*DIANTHUS CARYOPHYLLUS*, SHOWING ITS FIVE PETALS.

Five is a notable number in plantdom. All the members of the great class of Dicotyledons, to which the Dianthuses (Pinks) belong, have the parts of their flowers in "fours" or "fives." In the Monocotyledons (grasses, lilies, orchids, etc.) "three" is the significant figure.

THE EVOLUTION OF EXCHANGE.

BY WILFRED MARK WEBB, F.L.S.

A PROVERB, born of that one-sided argument which scientific training should soon dispel, stigmatises money as being "the root of all evil." The fact that everyone finds it necessary to become possessed of money is, perhaps, no refutation of the statement, but the slightest consideration will show how enormous is the debt which civilisation owes to media of exchange. It is difficult indeed to imagine anyone but the most primitive savage who could at the present day obtain everything needful for a comfortable existence through his own unaided endeavours. Recourse has to be had to the process of barter or exchange, to all intents and purposes, universally. Again, it is unlikely that each individual would find just so much of everything as his body requires or his soul longs for. Experience points to there being a superabundance of this and a corresponding lack of that.

Another difficulty may also arise, for, in ordinary barter, two sets of conditions have to be satisfied at the same time. Each party must need what the other has to spare

The hunter who has succeeded in finding someone who wants meat may, however, accept, say, cocoanuts, and, armed with these, he may have a better chance of getting the bread of which he stands in need. Cocoanuts are in this case a good example of a primitive currency. Even granting that by good luck bread can be straightway obtained for meat, it would not be easy to determine offhand how much or many of one should be given for the available quantity of the other. If a recognised currency exists, each commodity may be expressed in terms of that currency, and a fair bargain be the result.

In restricted areas it does not matter much if the currency is comparatively unwieldy and difficult of conveyance from place to place, but when such goods have to be carried long distances they are not always acceptable. Among the more primitive media of exchange which we may consider at this point are those commodities which can without loss be put to their original use by their owners. The actual things which get pressed into service are marvellously varied, and differ, as may well be expected, according to the pursuits and stage of civilisation of those whose choice falls upon them. Millstone

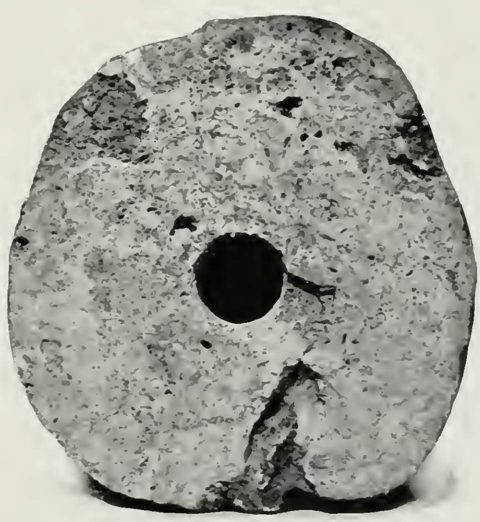


FIG. I.—MILLSTONE MONEY.

This curious currency is made in the Pellew Islands from coral rock and exported to the Carolines.

"money" (Fig. 1) is a striking illustration of this.

Those peoples whose chief occupation is the chase will have little but the skins of their quarry, and such lasting portions

as tusks and horns, which they can use for purposes of barter. There is, too, abundant evidence that furs. and so forth, were in early times used as currency, and comparatively recently this was recognised in the traffic of the Hudson Bay Company with the North American Indians. A "skin" was taken to be that of a beaver, and was worth as much as the fur of two martens, or two shillings.

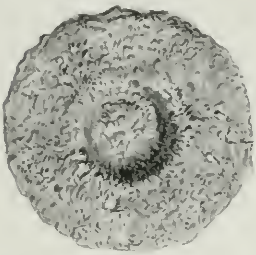


FIG. 2.—A MONGOLIAN DISC OF TEA.

I shall have a word to say about skins when we come to deal with matters which relate to money proper; I need only now allude to the fact that, at the present day, those mentioned are valuable chiefly for ornaments, though in primitive time they were necessary for clothing.

Fishermen have not quite the advantages of the hunter or trapper, but they have got over the difficulty by preserving the surplus from their catches. In the fifteenth century, stock-fish or dried cod was current in Iceland, and it was used also so late as the nineteenth century in Newfoundland. Fish, too, formed a medium of exchange in the Malay Archipelago until the year 1820.

FIG. 3.—RUSSIAN BRICK TEA.

We have very soon chanced upon a case in which food has a second use, and there are, as we shall see, very many others. Nomadic tribes and pastoral peoples employ live-stock as currency, which may be killed for eating if required, and agricultural communities take advantage in a similar fashion of the produce of the earth. An amusing story is told by a French *prima donna* who, while touring round the world, sang at an entertainment in the Society Isles, and was to be paid one-third of the receipts for her share in the performance. Her remuneration, she says, consisted of three pigs, twenty-three turkeys, forty-four chickens, and five thousand cocoanuts, besides considerable quantities of bananas, lemons, and oranges. In the Paris markets, as the *artiste* pointed out, this produce would probably have sold for four thousand francs, which would have paid her well for singing five songs; but as coins were scarce in the Society Islands, and there was more food than the singer could very well consume forthwith, she had in the meantime to feed her pigs and poultry with the fruit.

FIG. 4.—A JADEITE AXE-BLADE.

This is the equivalent in value of a fat man for food in New Caledonia.

Cattle are commonly accepted as payment among the less civilised nations, as they were in the time of the old Greek writers. Pigs used to pass current in Tibet, as chickens did in the Maldive Islands, and as buffaloes do now on the borders between Assam and Burma. Cocoanuts are still used for making purchases in the Nicobar Islands. A packet of twelve needles will cost you as many nuts, a packet of matches sells for twenty-four, while red Turkey cloth is valued at as many as a thousand cocoanuts per piece. In civilised India, until quite recently, bitter almonds formed a medium of exchange. Cloves played the same part in the Moluccas in the sixteenth

century. The employment of tea is, perhaps, better known. In the Shan States, balls of this commodity are current; disc-shaped cakes (Fig. 2) are met with in China, where custom permits of their being broken into pieces for the purpose of making smaller payments. They are made of a definite weight, and fourteen of them are worth half a sovereign. In the same countries, and in Russia, tea is made into bricks (Fig. 3), some of which bear an official mark.

Sugar was the legal tender in Barbados between the years 1640 and 1715, and at one time all the accounts and books in the offices of business men were kept in terms of sugar instead of pounds, shillings, and pence. Salt, to turn to a condiment of a different nature, has been circulated in Abyssinia, Sumatra, Mexico, and other places. It is still used in China, Burma, and on the shores of Lake Tanganyika. In the last locality it appears that large amounts are used, seeing that twenty pounds weight would be given for no more than a couple of yards of calico. In other places greater value is attached to salt, and the small blocks into which it is made are protected with leather. In Tibet "moulds" of salt used to weigh half a pound apiece, and twenty-four score of them had the value of one ounce of gold.

FIG. 5.—IRON HOES OF THIS TYPE CIRCULATE IN CENTRAL AFRICA.

Payments have long been made all over the world in corn, and the latter, in the case of corn rents, has formed a standard of value which in the past did not depreciate to such an extent as money. The colleges of Oxford and Cambridge Universities and Eton College for this reason owe much to the Act of Parliament passed in the time of Queen Elizabeth, which compelled them to lease their lands for corn rents. Rice is current in Burma, and as only the broken grains which are unfit for food or for sowing are employed, we come to a currency which may legitimately be looked upon as money, seeing that the material of which it is made cannot be used for anything else but purposes of exchange. The damaged grains can be obtained year after year, but not in overwhelming quantities; and it is evident that whatever is chosen as currency must be forthcoming when required but sparingly, so that its value may not be depreciated.

FIG. 6.—A CONVENTIONALISED SPEARHEAD (A) AND ITS PROTOTYPE (B) FROM CENTRAL AFRICA.

Before going on to consider money proper and its general development from merchandise, there are one or two examples of the employment of non-edible substances and manufactured goods to which we may allude. Mahogany was used in British Honduras to settle accounts at the end of the eighteenth century. It was with tobacco that the Virginian settlers paid for their wives, or rather for the passages of the young women who were sent in consignments to their country. The early colonists of Barbados adopted the same material, and it was also used in the Bermudas. An oblong mass of beeswax, with a rattan cane cast in it for convenience in carriage (for the

arrangement weighed thirty-four pounds), was at one time current in Borneo. Material for clothes, of European or native

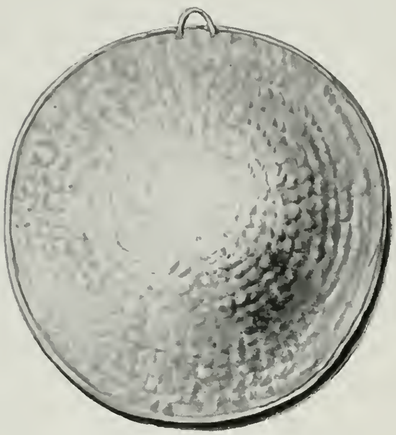


FIG. 7.—FRYING-PAN MONEY (ASSAM).

This type of frying-pan is somewhat conventionalised, but it can still be turned to its original use, if desired.

manufacture, as is well known, has proved exceedingly useful in the connection which we are illustrating.

Weapons and tools, again, form convenient media of exchange, and it has been suggested that the more or less highly finished flint implements of ancient make, which are found in large numbers,

FIG. 8.—"TABUA" OR WHALE-TOOTH CURRENCY (FIJI ISLANDS).

The Cachalot whale furnishes the "needful" in this case.

were used as such. Certain it is that stone axes were current in New Guinea before they were replaced by metal ones, and a jadeite axe-blade (Fig. 4) in Marie Island would in cannibal times have purchased a plump individual for purposes of food. Shields might be mentioned, and the copper ones of the North American Indians were worth five hundred (beaver) skins. Spear-heads, arrow-heads, knives, and even spades and hoes (Fig. 5), have all played, and still do play, their financial part, as we shall see.

A very interesting stage is reached when natural productions or merchandise are

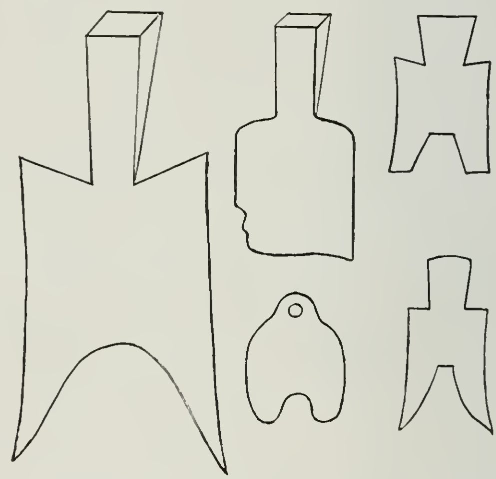


FIG. 9.—EARLY CHINESE SPADE AND SHIRT MONEY.

B.C. 2255 is the date given by some authorities for the employment of this novel "money."

exclusively used as coins would be; when spear-heads (Fig. 6, A) never see a battlefield and hatchets never chop. Then sharpness of point and keenness of edge are no longer necessary attributes. Size and shape are much more important in regard to convenience in handling. Gradually the implement or utensil becomes conventionalised and allowed to degenerate. "Imitation" hatchets circulate in West Africa. In the central parts of the same continent the spear-head currency is no longer of the offensive type suggested, and the

spade blades, also used as coins, are manufactured in Europe. The hoes seen on the White Nile are still capable of being employed in husbandry, and are therefore not truly money, like those to be seen on the Congo. The metal frying-pans of Assam (Fig. 7) are somewhat conventionalised, but could at a pinch be used for cooking; while the knives of the Kachins are only such in name.

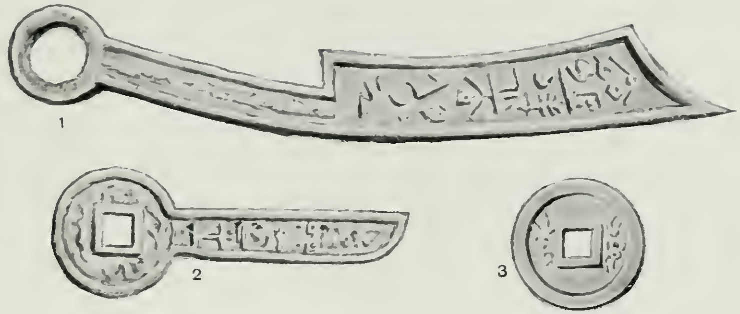


FIG. 10.—CHINESE "CASH," AND HOW IT ORIGINATED.

Knife and razor "money" (1 and 2) was the original form, but the length of blade was a hindrance. The blade was gradually shortened, until nothing but the convenient tag (3) was left.

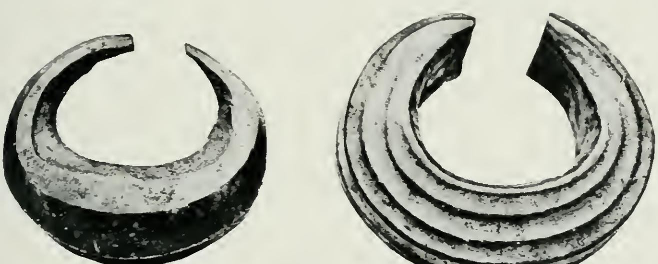


FIG. 11.—RINGS OF BRONZE AND IRON.

These are used by the Basoko tribe (Congo Free State). The value of the rings depends upon their size: the larger of the two here shown is worth about 8s.

China, with its long history of a peculiar civilisation, furnishes an excellent instance of the evolution of metallic money. Anyone looking at the round "cash" (Fig. 10, 3) with square holes in the centre would, without knowing its ancestry, so to speak, see only a more or less ordinary coin, pierced, however, so that strings of similar ones may conveniently be carried. We find that the older currencies consisted of various conventionalised objects, whose prototypes are evident or not, as the case may be. We have "spade" money (Fig. 9) and "razor" money both in use hundreds of years before the Christian era, while some others ascribe an age of more than four thousand years to the first-mentioned type. Then there is "shirt" money (Fig. 9), some of which is as old as those already mentioned. Many of the "coins" are perforated, and when we come to the knife money (Fig. 10) of the usurper Wang Mang, who reigned from A.D. 9–23, we find that the pierced end is rounded and enlarged, while the hole is square; in fact, if the "blade" were removed it would be exactly like the "cash." Hence the latter are merely the useful loops, which is all that has survived of the various objects which once were useful implements.

The spoils of the chase, which we have already mentioned as being among the

FIG. 12.—TUSK-SHELL MONEY (WEST COAST OF NORTH AMERICA).

most primitive currencies. have also furnished us with money in the shape of leather. A suggestive theory as to the origin of leather money of comparatively small size claims that when skins were current little pieces were clipped from them and given to the purchaser. when they were not at once carried away on the completion of a bargain. The possession of the fragments, which might have in the meantime changed hands in some other transaction, would be taken as proof of the ownership of the skins into which they could be fitted. The proceeding would be much like the production of bills of lading at the present day. If we further imagine that the small pieces of skin continued to change hands, and the claiming of the skins was put off *sine die*, the former would practically be looked upon as money, and a leather currency could easily be established when once people became accustomed to acknowledge the value of such representative money. Leather money was used in Russia, and tradition ascribes to ancient Rome a similar arrangement. Rulers have always been fertile in ideas for raising funds, and an Emperor of China, shortly before the year A.D. 1, obtained a monopoly of white deer skin, of which the currency was made, by collecting all the animals which possessed the necessary covering into a park, and forbidding any other person to keep them.

FIG. 13 — A CORD OF ROPE MADE FROM FLYING-FOX HAIR (LOYALTY ISLANDS).

It will be allowed that personal ornaments have at the present day an intimate connection with the wealth of the owner. It is not hard to imagine that objects which vanity made valuable should often be used as currency, while in times and in climates where pockets are not known it might be very convenient to wear one's wealth upon one's person. Again,

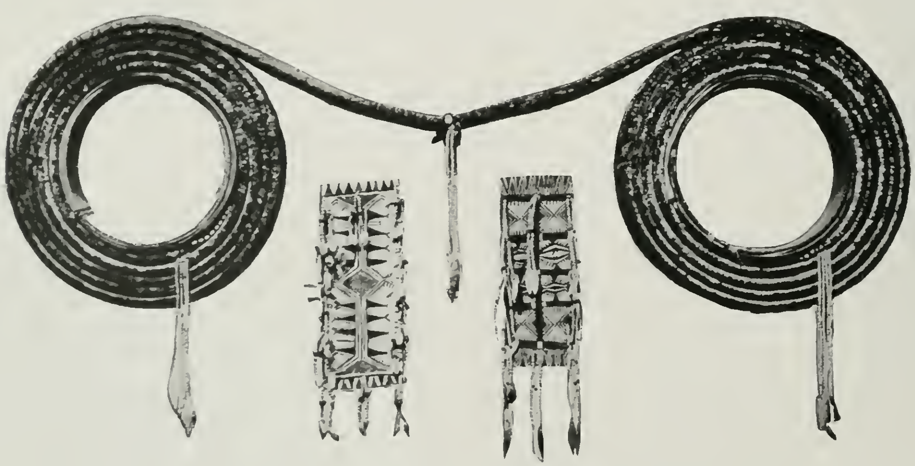


FIG. 14.—FEATHER MONEY (SANTA CRUZ ISLANDS).

A band of vegetable fibre is covered with parrot feathers. The two boards are hung in the middle, and the whole is carried in a bag.

the desire for display might lead to a similar use of riches. It seems likely that the various teeth (Fig. 8) and bones that form money (not to mention feathers) (Fig. 14) may have first of all been utilised as decorations merely. The teeth of porpoise and dog, among others which are used in the South Pacific Isles, may be mentioned here as a case in point. The North American Indians of several tribes adopted the eye-teeth of the wapiti, each being valued at twenty-five cents of U.S.A. money. The stranger choice of the lower jaws of flying-foxes is difficult to explain in any other way than that originally they were worn upon the person. Hair from the ears of the same creatures has been pressed into service in New Caledonia and elsewhere (Fig. 13).

Ornaments in the form of armlets of plaited fibre constitute money in Borneo; others made of shell are put to a like purpose in the Solomon Isles. Ring money (Fig. 11), a survival of the old Roman bracelets, is well known, and is still current on the Lower Congo and the Bonny River. It will be well to consider the question of shell money at this point, as the beauty of the molluscan coverings must have had much to do with their adoption in the first place, though the comparative imperishability of shells must have commended them to the primitive financier. It stands to reason that the species adopted must not be too easily obtained, though this difficulty may be got over by subjecting the shells, or parts of them, to a process of preparation which entails considerable labour, and militates against the too easy making of money, in the literal sense of the words. The tusk shells (Fig. 12) used on the west coast of North America cannot be obtained without much trouble; and, indeed, they are only gathered in small quantities at a time from comparatively deep water by means of a long-handled rake. The word *cowry* signifies money, and four thousand shells of the common species used as currency were worth a shilling in India. The great bulk of such shells (Fig. 23) are used in Africa, and hundreds of tons have reached a single port on the West Coast in one year. It has been pointed out that, as the local dealers buy the shells by weight and exchange them according to number, the smaller the shells that will pass muster among the natives the more profit for the importers. Numbers of other shells are used whole or with the apices removed, so that they may be strung together; but the "shell money" proper is what early visitors to North America found in circulation among the Indians under the name of *wampumpeag*. "Wampum" (Fig. 17) consists of small perforated discs cut from a bivalve shell; those made from the bulk of the valve are white, and worth but half as much as those of a similar shape cut from its purple border. This currency was made legal in Massachusetts at the beginning of the seventeenth century.

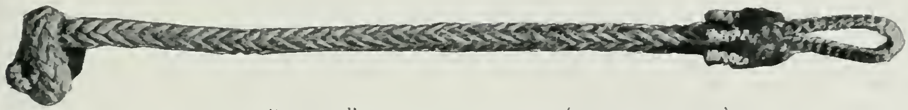


FIG. 15.—"OVNEP" OR SPEAR-THROWER (NEW CALEDONIA).

This is of considerable local value when well ornamented with tufts of flying-fox hair.

FIG. 16.—"DEWARRA"—THE CURRENCY OF NEW BRITAIN.

This is made of the shells of a dog-whelk threaded upon ribs of palm leaves. It is priced at 3s. a fathom, and a few fathoms make a presentable necklace.

A very interesting kind of money, which is used in New Britain, is made by breaking away portions of a small dog-whelk and threading the main part thus left upon leaf-ribs (Fig. 16). It is an instance of money which is somewhat restricted in its use, and it may be remarked that several currencies may exist in the same locality, each being used for a recognised transaction. The natives of New Britain will not take gold in exchange for their whelk-shell *dewarra*, and will not sell valuable things like canoes for anything else. The "dewarra," which is worth three shillings a fathom, is hoarded, and the store may be worn as a gigantic necklace. It is customary to produce at rich men's funerals the whole of their dewarra, and ultimately to distribute it among those present.

Discs similar to wampum and various beads cut from shells are in circulation in the Pacific Islands (Fig. 20). Glass beads are other objects of adornment which play a great part in some districts. Among the beads still to be found on the West Coast of Africa (Fig. 18) are a kind known as "aggries," similar to those made in Egypt in the seventeenth and nineteenth dynasties, and which formed the currency of old Arab traders, who brought them from Egypt.

The Portuguese and Spaniards copied the beads, which are still made in Venice. One ancient variety of similar origin, called "blue popo beads," are worth more than their weight in gold, and even the Venetian bead makers cannot imitate them sufficiently nearly for the natives to accept them.

Gold and silver owe their use to their ornamental value. At first the payment made in these would be weighed as gold is now in China, and as coins have been when very much lighter than they should be, owing to the tricks of moneyers or subsequent wearing or clipping. To save this trouble, bars of metal were made of recognised size and counted, and when an impression similar to that produced by a seal was made upon them by some state official, it acted as a kind of guarantee. The silver "Larins" of Persia (Fig. 19) form a case in point. The production of a design which practically covered both sides made it obvious that the coin bearing it intact retained its original and proper size, and had not been tampered with.

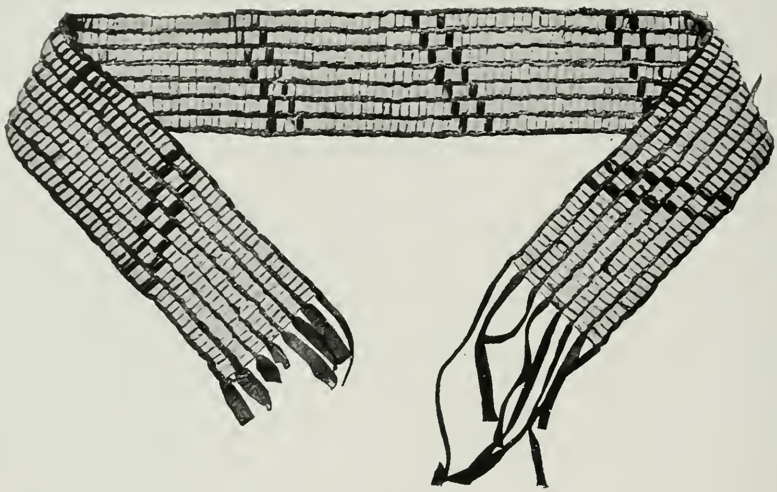


FIG. 17.—A BELT OF WAMPUM (NORTH AMERICA).

It is interesting to trace the connection

between the first coins, which were of gold and made in Asia, with our modern bronze penny. The Greek *drachma* was a silver copy of the early productions just alluded to, the Roman *denarius* perpetuated the latter and gave rise to the Saxon silver *sceatta*, which in turn developed into the Saxon silver penny. This still remains in our Maundy money, and was struck in copper in George III.'s reign, finally being altered to bronze in 1860 (Fig. 21).

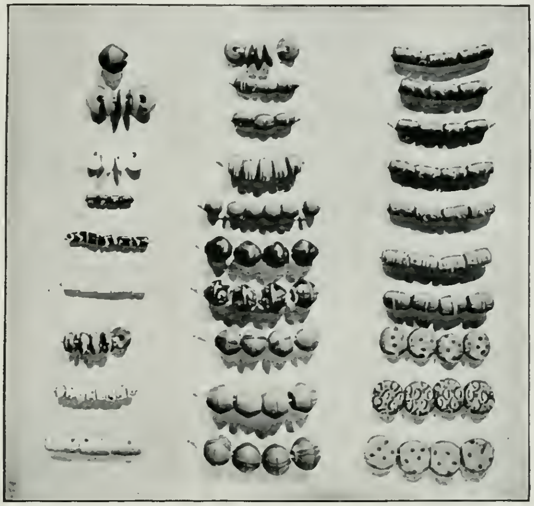


FIG. 18.—BEAD MONEY USED BY TRADERS IN CENTRAL AFRICA.

Some types of beads are taken in exchange for gold; others are required when slaves are in question.

FIG. 19.—PERSIAN "LARIN."

This is made of silver, and is frequently ornamented with a device, as in the sample depicted.

We have seen that there is such a thing as representative money which is simply a pledge or token, and at the present day, when silver and bronze are very cheap, all except our gold coins belong to the category of authorised tokens. In the days when there was no copper money in this country private persons struck tokens, which they undertook to redeem upon presentation. There is no doubt but that these must have been very useful, and James I. and Charles I. issued farthings, but they were never made legal tender.

The representative money which is most familiar and is the highest development of currency is, of course, paper money. This was used in China from

FIG. 20.—SHELL MONEY IS ALSO EMPLOYED IN THE SOUTH PACIFIC ISLES.

In this case it may take the form of a necklace.

A.D. 800–1400, and representative money of other characters was not unknown among other ancient peoples. The cheque system of modern times saves a prodigious amount of interchange of coins. At the clearing-house the amounts owed to any particular bank and to each of the other banks are considered in connection with the amount it owes to them individually, and only the difference, often comparatively small, changes hands as the result. Foreign bills of exchange bring us back to barter, but of a glorified nature, and carried out with the help of money. For instance, a bill drawn upon an English buyer of skins from South America might in that country be sold to a local merchant who is importing cloth from England, and after being sent to the latter place by post as payment to the manufacturer he would receive cash from his fellow-countryman who deals in skins.

In new countries and under exceptional circumstances the temporary use of representative money in the form of paper or parchment is often a very great convenience.

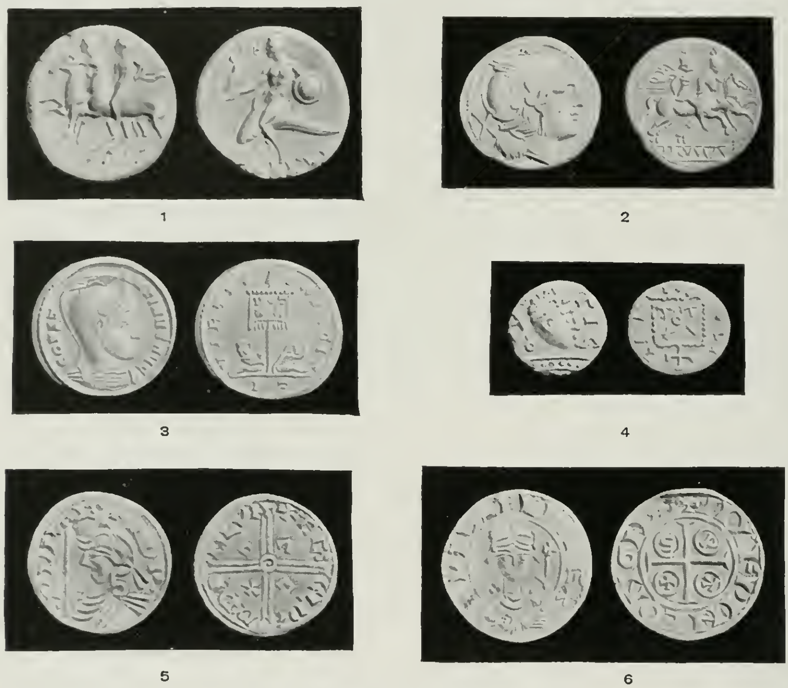


FIG. 21.—SOME INTERESTING COINS.

1. A Greek "didrachma": coin of Tarentum (about B.C. 350), the prototype of the Roman "denarius" or penny.
2. A Roman "denarius" or silver penny.
3 Coin of Constantine the Great, from which the Anglo-Saxon "sceat" (in 4) was copied.
4. A Saxon "sceat," the forerunner of the Saxon penny. We refer to this when we say that "there is not a 'shot' in the locker.'"
5. A Roman silver penny.
6. A Norman silver penny. This was struck by William the Conqueror, and only coins of this value were used by members of his dynasty.

Of the latter material is the money adopted by the colonists in the Cocos-keeling Islands. During the siege of Mafeking paper money was manufactured, the designs made by General Baden-Powell (Fig. 22) being copied by photography, and the actual notes printed from the negative on sensitised paper.

One great advantage of paper money is its lightness and the ease with which it

may be carried about, though much wear and tear makes the notes, which are much circulated and not often replaced by others, exceedingly dirty and more liable to spread disease than metallic coins.

All kinds of precautions have to be adopted in order to prevent the counterfeiting of banknotes, such as the secret preparation of special paper and ink, the introduction of watermarks which are difficult to copy, and of private marks which are unknown to the public. At one time, for instance, the Bank of England notes, it is said, were printed with a vegetable ink obtained from the ink fungus, and containing thousands of its minute black spores. A simple microscopic examination of the surface of the printing at once told whether the note was genuine or not, and any alteration that had been made could

FIG. 23.—COWRIES

be easily distinguished owing to the removal of the spores.

The history of banknote forgery is indeed an interesting one, but it is beyond the scope of the present article. Let us

FIG. 22.—TEMPORARY PAPER CURRENCY: A £1 NOTE USED DURING THE MAFEKING SIEGE.

Taken from the first print from the negative. By the courtesy of Messrs. Ilford, Ltd.

consider for a moment the objections to paper money. It tends to drive out coins, and may become a currency which replaces them entirely, and with lamentable effects, owing to over-issue and the depreciation which follows.

The frauds which may arise through the cheque system, to which I have already alluded, are many, and here again all the art of engraving and machine turning has been brought into play. Inks are used which show the slightest attempt at tampering with the writing upon the cheque, and various devices are adopted to ensure the draft being taken direct to bankers, while perforated figures prevent the possibility of larger sums being transcribed should other means fail.

With care, however, the difficulties and objections to paper currencies which are promissory notes can never equal the advantages.

THE VAGARIES OF BRITISH WEATHER.

By ARTHUR H. BELL.

(Assistant, Meteorological Office, Victoria Street, S.W.).

THE weather of the British Isles is probably the most varied in the world, for although the different meteorological events lack the vigour displayed by the atmospheric demonstrations in other regions of the earth's surface, they easily take first place as regards the rapidity with which they change their moods and aspects. British weather is indeed abnormally kaleidoscopic; but, thanks to those observers who have so patiently and continuously noted and recorded the atmospheric conditions that accompany these protean antics, the causes of these quick transformations are rapidly coming to be better understood. According to a cynical aphorism, "A fine day in England is like looking up a chimney, and a foul day like looking down one." But most people would say that King Charles II. made the more correct observation when he said that "no country in the world invited a man to walk abroad on so many days of the year as the climate of England." It must, however, be confessed that on some days the violent contrasts that occur in British weather appear most unaccountable, and it is not the least interesting part of meteorology that concerns itself with searching out the reasons for these sudden and oftentimes very trying vagaries.

Now British weather, like many other things, is made abroad; or, at least, the greater part of it is a foreign importation. In order, therefore, properly to trace the springs of the weather to their source, it is necessary, in the first place, to look far afield. The atmospheric changes that occur in the British Isles are, indeed, only a local phase of a general plan that is common to the whole world. The first thing to do, therefore, is to look on a map and see what is the exact geographical position that this region occupies. It will be still more informing if a synchronous chart be consulted, for this will show the position as regards the ocean currents and storm-tracks of the globe. Such a chart would show that the British Isles lie, as it were, right in the fairway of the storms that are so continually careering over the surface of the earth. As a rule, these storms are bred in an area that lies a few degrees north of the equator, a point that may be considered to be the commencement of the great storm-track that, like a great river, takes its way through the atmosphere (*see* Fig. 1). A short distance from this starting-point the track takes a decided bend to the north-east, a change in its direction that leads it directly to the British Isles. Many of these storms, indeed, move on a course that follows that of the Gulf Stream, which, as regards our weather, may almost be considered a national institution. It is, then, along this track that the bulk of the atmospheric changes are imported, and it is a fact that needs always to be borne in mind when studying the many vagaries of the weather.

Now, if these storms kept strictly to this track, there would probably be an uninteresting monotony about the weather, for the different parts of the country would always come under the same part of the atmospheric whirl. The storms, however, vary not only as regards their direction, but there are also many other modifications that may happen to them as they come swirling in from the Atlantic. Moreover, they vary as regards their depth, for they resemble nothing so much as the dimples, eddies, and tiny whirlpools to be seen in any running stream of water,

which, similarly to the larger vortices in the atmosphere, are for ever changing their size, depth, and, as the meteorologist would say, their intensity. These varying episodes in the life of a storm are, of course, best discovered by consulting a weather chart, upon which are drawn the *isobars*, or lines which show the way in which the atmospheric pressure is distributed over different parts of the country. Such a chart at once shows that these *cyclones*, or depressions, as they are sometimes fitly called, are not always of the same shape; while it still further reveals the fact that they vary very much as regards the rate at which they travel across the country. People are nowadays becoming more familiar with the meaning of many meteorological terms, so that it will here not be necessary to do more than say that bad weather is associated with the *cyclones*, or depressions, the fine days being distributed by the *anticyclones*.

Supposing that a depression be imagined as coming in from the westward (*see* Fig. 2), it is possible now to realise a few of the things that a weather prophet has to watch for when he essays to forecast British weather. There is, of course, a well-recognised sequence of occurrences connected with these revolving storms, a brief consideration of which helps to explain the changes during the passing across the country of one of these atmospheric eddies. Both at the back and the front of these systems the weather is of a well-recognised type, and meteorologists now know that the other quadrants of the eddy have also their own peculiar characteristics (*see* Fig. 3). Thus, as the storm first appears in the west, there will commonly be seen those beautiful cirrus clouds; while for a few hours the weather is as fine as could be wished. At this stage the observant would notice that halos had formed round the sun and moon, these phenomena being generally

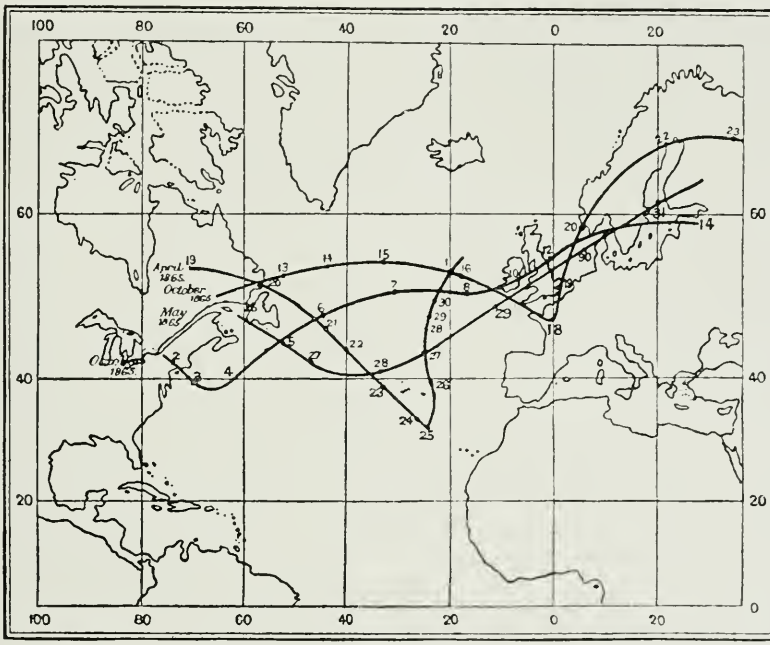


FIG. I.—CHART SHOWING STORM TRACKS.

The great storm-breeding area lies a few degrees north of the Equator. A short distance from its starting point a huge storm track bends to the north-east and makes for the British Isles.

harbingers of unsettled conditions. But very soon there comes a change, for the sky becomes rapidly overcast, the fine weather gives place to drizzling showers of rain, and the first transformation may be considered to have taken place. At this stage, also, the wind begins to blow hard and the barometer to fall with increasing rapidity. It will perhaps now be realised that if the storm happens to be one of those that are travelling at a high velocity, these changes will occur with a corresponding rapidity. As the storm passes overhead there is a lull in the force of the wind, while there is also to be seen that little blue patch of sky that is popularly said to be sufficient to make a Dutchman a pair of unmentionables, so that for a time the storm seems over. As soon, however, as the centre of the disturbance has passed, the rear of the depression commences to distribute the many unpleasant samples that it also carries with it. At the front of the system the temperature is comparatively high. Up to this point, moreover, the wind has been coming mainly from the south-west, but as the rear of the depression comes along the wind suddenly flies round to the north-west, and the temperature goes down with a run. Now, as already pointed out, these bad weather systems do not always pass across the country at the same rate of speed. Some of them, indeed, take a day or so to make the journey from one side of the British Isles to the other; while,

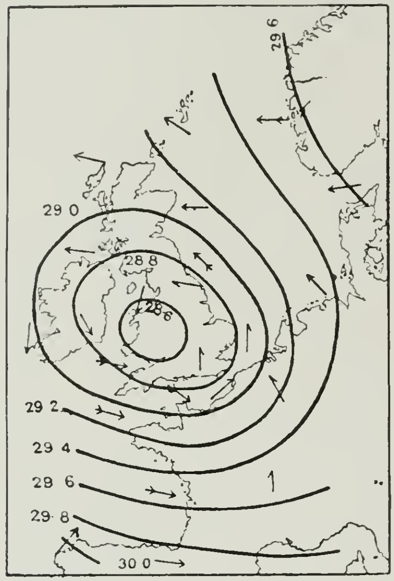


FIG. 2.—A TYPICAL "CYCLONE" SYSTEM.

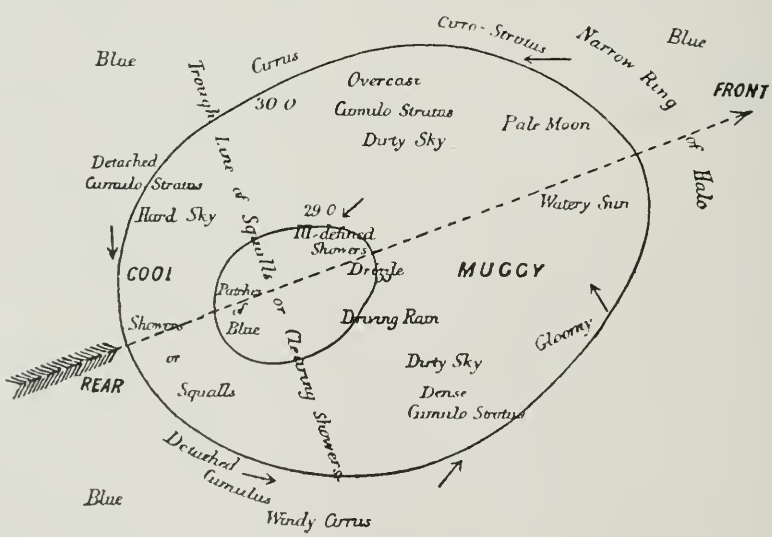


FIG. 3.—AN EDDY IN THE STORM.

Within the area affected by this great depression the weather is decidedly unsettled.

Photo, H. Moyse, Barnes, S.W.

FIG. 4.—AQUATICS AT BARNES DURING THE GREAT FLOODS OF JUNE, 1903.

Within a space of a few days some seven inches of rain fell, and the inevitable result was disastrous floods all over the country. In London many streets were flooded, and hundreds of houses could only be reached by boat or after an uncomfortable spell of wading through very dirty water.

on the other hand, they may make the journey in a few hours. It is in the latter circumstances that the most sudden transformations are produced, for the weather at such times has something fresh to show every hour. This, then, may be considered to be the ground plan of the various types of weather that from time to time descend upon the British Isles, and it is a sequence of events that any observer may verify for himself with very little trouble.

Now, it may here be said that these vagaries have been commemorated in so-called popular weather lore, there being many proverbs and aphorisms that make it quite clear that this sequence of weather that accompanies the passing overhead of a cyclone has been recognised by shepherds, farmers, sailors, and others who are called upon to spend many hours of the day in the open air. Many of these proverbs have, moreover, received a sanction from modern meteorology, for when they are compared with a weather chart drawn after the most approved fashion many of them are found to have a sweet reasonableness. Thus, as already seen, there is an unusually large amount of moisture in the air at the front of a depression, so that when heads of households and others forecast rain because their corns are troubling them, or because the furniture creaks, or it may be because plants or animals exhibit certain unwonted movements, they are simply stating in a popular way their recognition of the fact that the forefront of a deep depression has arrived.

But probably the most varied weather comes from what are termed secondary or subsidiary depressions, which are offshoots, as it were, from the primary system. The larger storms are unpleasant enough, with their destructive gales and heavy rains, but for thoroughly bad weather they must give place to the secondaries (Fig. 5). For instance, after one of these primary storms has passed and the weather seems to be settling down to better behaviour, this hope being encouraged by fitful gleams of sunshine, the rain will commence to fall, and continue to do so for twenty-four

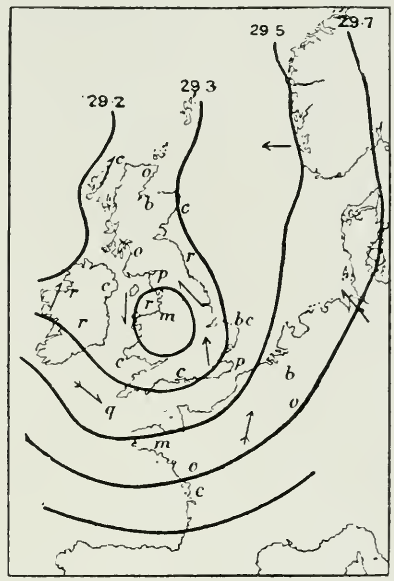


FIG. 5.—WEATHER CHART SHOWING SECONDARY SYSTEM.

The "secondaries" are worse than "primaries" as bad-weather breeders. The latter may bring gales and heavy lashing rains, but the former generally figure in a long wet day. Moreover, they are so fickle that they frequently upset the weather prophets' predictions.

hours on end. At another time these secondary depressions will contrive to develop a series of thunderstorms in different parts of the country, varying the proceedings, it may be, by precipitating heavy showers of hail or sleet. The temperature also goes through some rapid changes, so that within the space of a few hours the elements pass from summer to winter and back again. There is, however, an absence of wind with these secondaries, the sky at the same time being of a particularly depressing hue. This type of weather is more readily recognised from the oppressive or "muggy" state into which the atmosphere falls when a secondary is passing overhead. It is, indeed, these systems that so often puzzle the weather prophets, for they appear so suddenly that they do not always reveal

themselves on the weather chart, and hence it happens that a promised fine day sometimes turns out to be a thoroughly wet one. These wet and unsettled days are recognised by even the most unobservant, but in nearly every case it will be found that the vagaries exhibited were due to the fact that a primary depression had thrown off a satellite, as these secondary depressions are sometimes called.

It should here be noted that there are certain causes that produce modifications in the general characteristics of cyclones and their secondaries, and in order thoroughly to follow the weather through some of its more easily recognised intricacies, it is necessary to pass a few of these causes in review. In the first place, for instance, cyclones differ very much as regards their intensity, while there are also other modifications connected with the size and shape of the system. But probably the most important of these modifications are those that are impressed on the cyclone by local circumstances. It is, for instance, well known that thunderstorms are affected by the contour of the ground over which they pass, some parts of the country being much more liable to these electrical demonstrations than others. A mountain range will obviously exert a marked influence as regards the rainfall, while the effects introduced by a lake, or, in a still greater degree, by the sea, are also no less obvious. In order to predict the weather in an ideal way, it would be necessary to issue a special forecast for each locality. The vagaries that the weather exhibits as regards temperature and rainfall are especially to be traced to these local modifications, which are responsible for producing those violent contrasts so often observed in different parts of the country. There are also those seasonal variations that occur in the characteristics of the cyclones, the latter being larger, for instance, in the winter than they are in the summer, the position of the cloud and rain areas being also not quite the same during the two seasons. These, then, are a few of the causes to be looked for by anyone attempting to unravel the mysteries of the weather.

Many vagaries also are elucidated when it is remembered that in the British Isles the changes, or sequences, of the weather take place from west to east. This also is a fact that has been recognised in weather lore, the proverbs and popular prognostics based on a recognition of this fact being current in all parts of the country. Thus, when it is said that "A rainbow at night is the shepherd's delight," it simply means that the rain is to the eastward of the observer, and may therefore be expected to pass away, thus giving promise of a fine to-morrow. On the other hand, "A rainbow in the morning is the shepherd's warning" because the rain is now in the west, and may accordingly be expected to pass over during the day, and hence the success of the prognostic. This sequence of weather is to be observed in many other cases, and it is, indeed, the recognition of this fact that has made it possible to issue storm warnings and weather forecasts. In passing, it may be said that many people have the impression that much of the British weather comes from America, and they believe that it is possible to trace storms from one side of the Atlantic to the other. It was this belief, indeed, that for a time caused forecasts of the weather to be sent to the British Isles from America, for it was thought that if word was sent that a storm had set sail, as it were, from the other side, it would be possible to anticipate its arrival on our shores. No great measure of success attended the sending of these messages, and they were therefore discontinued. Storms do undoubtedly make the journey from one side to the other, the course they pursue being best shown by some of the larger weather charts. During their journey across, however, many of the storms lose their individuality ; or it may be that two

of them become rolled into one, or they may disappear altogether, and hence it is

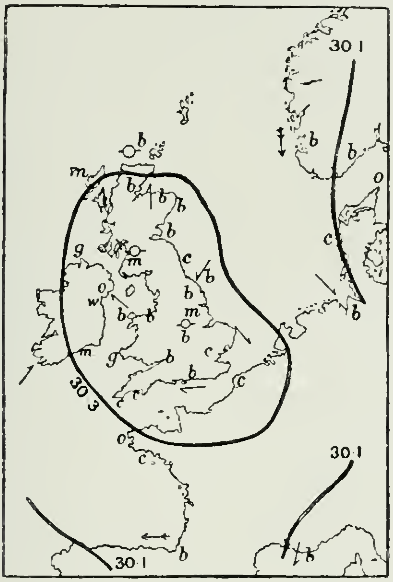


FIG. 6.—A TYPICAL ANTICYCLONE.

Fine weather may be expected within the area covered by the anticyclone.

that such messages are of very little practical value.

Now, as already seen, the cyclones are mainly responsible for the bad weather; while the finer days are associated with that form of distribution of atmospheric pressure known as "anticyclonic" (Fig. 6). With this latter system the weather is of a quiet and exhilarating description, but from many points of view the changes are quite as violent as those associated with the cyclones. Thus on a typical anti-cyclonic day the morning opens with mist and dew, or, if it is winter-time, there may be fog and hoar-frost. The latter phenomenon is noted for the eccentric manner in which it makes its appearance, and affords an illustration of the curious way in which different parts of the atmosphere vary as regards their temperature and moisture. Moreover, the suddenness with which the sun drives away the fog, mist, dew, and hoar-frost is often very noticeable, the transformations thus produced being among the most rapid that our climate has to show. It should also be remembered that during an anticyclone there is little or no wind, the air-currents, as a rule, amounting to little more than a slight breeze. A further point to be noticed as regards anticyclones is that the winds are circling in the opposite direction to what they are in a cyclone. This is, of course, a very elementary fact, but it is one of very great importance when one is seeking to follow the vagaries of the weather. The shape of the "isobars" is commonly circular, or very nearly so, the barometric gradients, as they are called, being very slight.

In the winter the anticyclonic systems produce those cold days and intense frosts so much appreciated by skaters; but in the summer they seem almost to change their character, for they now become responsible for those very hot days and brilliantly hot spells that even a British summer can show if it happens to be in the mood. These very hot days, more-

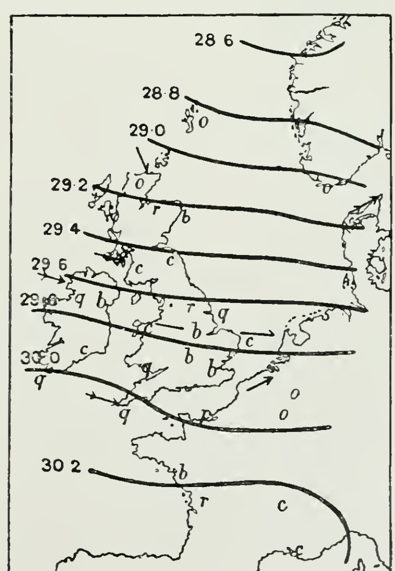


FIG. 7.—STRAIGHT ISOBARS ASSOCIATED WITH VISIBILITY AND AUDIBILITY.

over, very often come along after a rainy interlude, and people sometimes seem at a loss to account for the sudden change.

In looking for an explanation of this vagary the first thing to call to mind is the fact that in an anticyclone the air is commonly extremely dry, a condition of things that is quite the opposite of what obtains in a cyclone. Moisture, indeed, acts as a protecting shield between us and the sun's rays, the presence or absence of this moisture regulating the amount of sunshine that falls upon the various areas of the earth's surface. When, therefore, an anticyclone is poised overhead, the chances are that there is very little aqueous vapour between the earth and the sun, so that the heat rays pass easily downwards and produce a very hot day. As a rule, when anyone finds himself experiencing unusually brilliant and cloudless weather, he may commonly ascribe these pleasant conditions to the fact that he is on the south-western edge of a very large and throughly well-equipped anticyclone. Curiously enough, this same quarter is the scene, so to speak, of the intense frosts, a quarter in which it may, therefore, be said that extremes meet. In the winter the thin canopy of cloud that forms overhead during anticyclones is not sufficiently thick to develop rain, but it serves to assist the forces of radiation, so that in these favouring circumstances the surface of the earth grows rapidly cool, with the result that the temperature falls to a very low point. These curious contrasts produced by the anticyclones in winter and summer must have been observed by nearly everyone, and by applying the general principles outlined above it will be found that much of the mystery connected with their arrival will disappear.

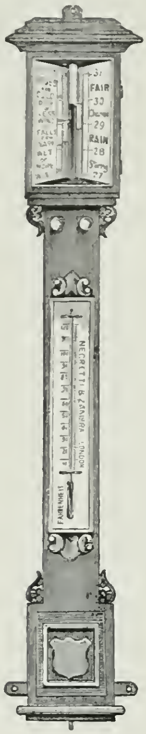


FIG. 8.—COMBINED THERMOMETER AND BAROMETER COMMONLY SUPPLIED TO FISHING STATIONS.

It should also be noticed that anticyclonic weather may often be recognised by observing the behaviour of plants and animals, and more particularly those of the birds. There is an exhilarating feeling noticeable, so that they go farther afield, and animals display an unwonted activity. Human beings also respond to this stimulus due to the increase that has taken place in atmospheric pressure, and they lose that feeling of depression that they complained of when the cyclones, with their damp and muggy weather, were passing overhead. These vagaries, not only as regards the atmosphere, but also as regards what may be called the physiological effects, may all be traced to the difference that exists between cyclonic and anticyclonic systems.

Having thus laid down what may be called the ground plan of the weather, a glance may now be given at the modifications that occur as regards the relation which these cyclones and anticyclones have to one another. Broadly, meteorologists divide all weather into one or other of these two types, but there are days when neither of these systems appears to have the upper hand, the behaviour of the weather in such circumstances being of a most varied character. Thus it will often happen that the day opens after the usual manner associated with anticyclonic weather, the movements of the barometer and all the other omens leading the inexpert in weather matters to expect that an enjoyable time is coming; and then, almost without any warning, rain sets in and the atmospheric conditions become thoroughly unpleasant. In this case what has happened is that a tongue of high

pressure has been thrust in between two cyclonic or bad weather areas. This strip of fine weather is sometimes called a "wedge," and, as a rule, it springs up just in front of an advancing depression and travels in its company. As already seen, there is an interlude of fine weather at the rear of a departing cyclone, so that in the wedge that immediately follows it the air is often extremely dry, with the result that the sun's rays have great burning power. The deceptive nature of this kind of weather has been recognised, and in popular language it has been described as "being too bright to last." This kind of weather may also be recognised by those curious clouds that appear in long strips, and which since they look something like the ribs of a ship, have received the name of "Noah's ark." At such times as these people will often remark on the clearness of the atmosphere and the distinctness with which distant objects may be seen. This extreme visibility has, time out of mind, been a popular prognostic for rain, and it is, indeed, one that may be depended upon. As previously mentioned, closely following the wedge, there is a cyclonic system with its rain. At such times the barometer rises for an hour or more, so that heads of families and others, being deceived, forecast fine weather. But for the reasons given above such a prophecy is doomed to failure. These wedges of fine weather should therefore be carefully looked for, as it is with them that is associated that very curious vagary of a rising barometer being followed by rain. It may perhaps be briefly pointed out that thunderstorms frequently occur with these wedges, a circumstance which adds still further to the variety provided by these curious interludes. Commonly the storm occurs at the apex of the wedge.

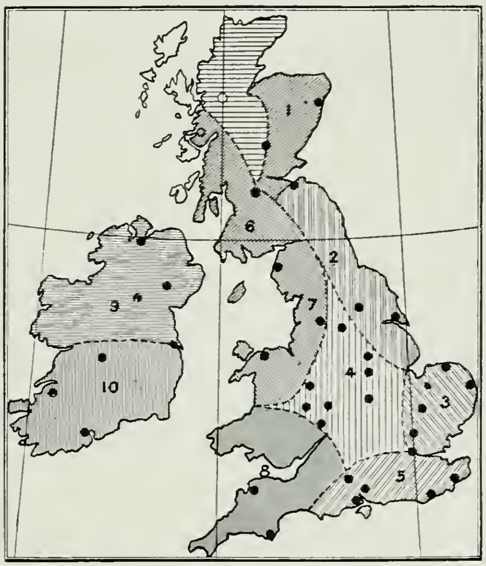


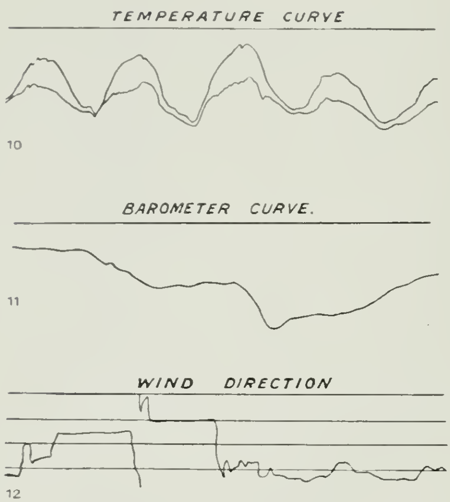
FIG. 9.—MAP SHOWING THE DISTRICTS INTO WHICH THE BRITISH ISLES ARE DIVIDED FOR WEATHER FORECASTS AND STORM-WARNING PURPOSES.

0, Scotland, N.; 1, Scotland, E.; 2, England, N.E.; 3, England, E.; 4, Midland Counties; 5, England, S., with London and Channel; 6, Scotland, W., with Isle of Man; 7, England, N.W. (and N. Wales); 8, England, S.W. (and S. Wales); 9, Ireland, N.; 10, Ireland, S.

There is another type of weather that rarely fails to attract attention, this being when the atmosphere is in that condition that distant sounds are heard very distinctly. The wind also is very gusty, so that the soot falls down the chimney and doors seem to bang in an unaccustomed manner. Overhead there is a canopy of clouds that has chinks in it, through which the sunlight pours down, this appearance being described as "the sun drawing water," a phenomenon that has always been considered to be a sign of rain. At such times people remark how clearly they can hear distant trains, waterfalls, weirs, the sea, and so on, this audibility being the principal thing by which this type of weather may be recognised. Now a meteorologist with a weather chart in front of him would note that at these times the isobars were nearly straight (Fig. 7), and that, like the wedges, they were not far removed from an advancing depression. It is the nearness of the depression that produces the anomalies in the weather that occur with

this type of distribution of atmospheric pressure.

Many of the points that have been referred to in the foregoing remarks will



FIGS. 10, 11, 12.—A LESSON IN CURVES.

In Fig. 10 the upper curve is the record of the dry bulb, and the lower of the wet bulb thermometer. Note that the barometer curve (Fig. 11) is not so complicated as are the curves in Fig. 10. The curve in Fig. 12 is from a self-recording wind gauge.

be further elucidated by looking at the weather charts shown in Figs. 1, 2, 5, and 13, which show the way in which a cyclonic storm comes in from the Atlantic and increases in depth and intensity as it journeys eastward. It will be seen that the barometric gradients become very steep (Fig. 13) and are in great contrast to the isobars in the anticyclone illustrated in Fig. 6. The figures on the charts refer to the height of the barometer, while the arrows indicate the direction of the wind and its relation to the trend of the isobars.

All these changes in the weather are recorded in a minute manner by the self-recording instruments, the principal matters recorded being the movements of the barometer and the thermometer (Fig. 8), the changes in the direction and velocity of the wind, the amount of rainfall, and the number of sunny hours. In Fig. 10 an illustration is given of the manner in which the temperature changes from day to day, the upper curve being the record of the dry bulb and the lower that of the wet bulb thermometer, the risings and fallings of the curve being a measure of the daily vagaries, not only of temperature, but also of the humidity. In Fig. 11 the way in which the barometer rises and falls is illustrated, the amplitude of the changes being, of course, much smaller than is the case with a temperature curve. Fig. 12 is a curve from a self-recording anemometer, and shows how the wind changes its direction from hour to hour. Figs. 4 and 14 need no explanation other than that given in the inscriptions beneath them.

The devastating floods of the June of 1903 afford a notable illustration of what is possible. The summer months of the year in question, indeed, established a record, the total rainfall for June, July, and August being the heaviest registered for at least forty years. But apart from meteorological statistics, ample evidence of the disastrous season was afforded by

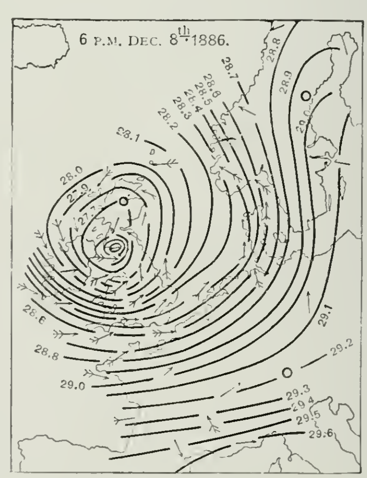


FIG. 13.—A DEEP CYCLONIC STORM, WITH STEEP BAROMETRIC GRADIENTS.

the agricultural reports, which showed that, both as regards rain and sunshine, the vagaries of the weather had been more than usually pronounced. Now at

such times meteorologists are continually asked for some explanation of this extraordinary behaviour on the part of the elements ; but the truth is meteorology is too young a science to give an adequate reply to so hard and complicated a question. There are, of course, many theories concerning these abnormal episodes, but so far none has met with general acceptance.

Thus some theorists declare that in 1903 there was a superabundance of ice in the Atlantic that caused the cold and the rain, but they do not say how. Others affirm that the vagaries were in some way involved with terrestrial and atmospheric electricity ; but, although this is an attractive suggestion, the evidence in support of it is slight. And then the "sun-spotters" offered their theories, and it must be conceded that there is much to be said in favour of the idea that it was some obscure changes in the sun that threw the weather of 1903 out of gear. After all, it is the sun that controls matters meteorological, and the study of his vagaries will doubtless go far to explain those of the weather.

Photo: Campbell & Gray, Cheapside, E.C.

FIG. 14.—FLOODED GARDENS IN JUNE.

Many of the gardens at Clapton, some of which are shown here, were under water during that memorable June of 1903.

HEARING.

IN studying any branch of science one of the most essential points, if we have no wish to be involved in hopeless confusion, is to define clearly every word used in a scientific or technical sense, and to take care that, once defined, the same word is never made to do duty for some meaning different from that which it was originally intended to convey. We have to be particularly careful in the case of words in ordinary use, for these are often used in a more or less slipshod fashion, and, unless strictly looked after, are likely to prove very dangerous stumbling-blocks to the unsuspecting student. The present paper gives us at once a case in point. Asked what is the organ of hearing, one naturally replies, "The ear." Asked to define the ear, it is equally natural to point out that gristly and fleshy appendage at the side of the head, which a barbarian taste has decided shall be cut in the case of terriers for the sake of symmetry, pierced in that of human beings for the insertion of some useful or ornamental article—snuff-box or ear-ring.

But a moment's consideration will convince the most unthinking that the "ear" in this sense of the word is not the organ of hearing at all. For deaf people, or people rendered temporarily deaf by a plug of cotton wool or the like, have this "ear" as perfectly developed as anyone. People who have had their ears cut off, and animals devoid of that appendage, such as birds, reptiles, and fishes, are, as common observation teaches, quite capable of hearing and distinguishing sounds. The sound of, for instance, a tuning-fork or a musical box can be made audible to deaf people by placing the instrument against their teeth, and the same thing can be shown by stopping one's ears tightly, and touching one end of a table or plank with the teeth, while another person gently scratches the other end of the piece of wood.

What all these facts show is that the organ of hearing is something inside the head, and that the sound waves which give rise to an auditory impression may, as under ordinary circumstances, be transmitted through the tube which we see passing towards the interior of the head from the "ear," or may, if this their normal channel is closed to them, be transmitted through the bones of the skull.

We must distinguish, therefore, the *external ear*, or ear commonly so called, from the *internal ear*, or true organ of hearing. The former, although of great use, can be dispensed with ; the latter is absolutely essential for purposes of hearing.

Let us now consider what are the essential conditions of our organ of hearing. What we call sound is due to vibrations of the air communicated with a certain degree of rapidity by the sonorous body*; and that any sound should be audible to an animal it is necessary, firstly, that there should be some part of the animal body so delicately poised, as it were, as to be set vibrating in unison with the sound, and secondly, that there should be, in connection with this same part of the body, a nerve able to transmit the vibrations to the brain. It is instructive to compare the essentials of an organ of touch with those of an organ of hearing. When any part of our body is touched, an impression is made on the skin, and this impression is communicated

* "The Sounds We Hear," CASSELL'S POPULAR SCIENCE, Vol. I., p. 542.

by a nerve to the brain: if the nerve is cut, that part of the body is quite without feeling. The skin, therefore, which is the great organ of touch, is able to receive and transmit to the brain, by its nerves, coarse vibrations produced by actual contact. If any part of the skin could be made so sensitive as to be set vibrating by sound waves, it would become an organ of hearing, and its nerve would become an auditory nerve.

The internal ear of the higher animal is a structure of such extreme complication that the best way to get a correct notion of hearing organs in general will be to consider the apparatus as it exists in the lower animals, where its structure, and the principles upon which it works, are sufficiently simple to be readily grasped.

No better animal can be selected to start with than the common lobster, as anyone sufficiently interested in the subject can readily make out the main points of its hearing organ for himself, by sacrificing to scientific purposes a small and insignificant portion of a lobster salad.

The lobster has two pairs of feelers, one long (the antennæ) and one short (the antennules), projecting from the front of its head. If one of the latter be removed by inserting the point of a pocket-knife between its near end and the socket in which it works, it will be found to consist of three strong, hard pieces, placed one above the other, and movably jointed together. The last of these pieces, that farthest from the head in the entire animal, has attached to it two jointed filaments about two inches long. These form the feeler proper, being organs of touch.* The first joint of the feeler—that nearest the head—is considerably larger than either of the others, and presents on one—the upper—surface an oval space, which is not hard and rigid like the rest, but membranous, or rather horny, being formed of a substance called *chitin*, the same substance as that which forms the soft interval between the hard joints on the under side of the lobster's tail.

At the farther end of the same joint,

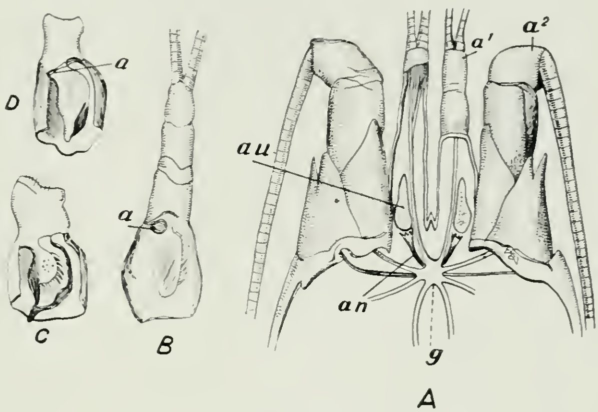


FIG. I.—HOW THE LOBSTER HEARS.

(After Furze.)

A, head of lobster, showing relations of auditory organ (au) and nerve (an); a^1, antennules; a^2, antennæ; g, brain.
B, base of antennule, showing the position of the auditory organ, a.
C, auditory sac, with hairs and "otoliths."
D, auditory sac, showing external aperture, a.

and to the outer side of this space, is a little tuft of hairs; in the middle of this tuft is a small hole, into which a bristle or even the head of a small pin can easily be passed. If, then, the whole lower side of the joint is cut away, and the soft stuff which fills it scraped out, the bristle is seen to have passed into a little transparent bag of "chitin," about a quarter of an inch long. On the lower side of this *auditory sac*—that is, the side we are now supposed to be looking at—there is a curved line of slightly different appearance from the rest of the wall. Careful dissection shows that the nerve passing from the brain to supply the feeler sends off a small branch to the curved line. This branch is the *auditory nerve* (Fig. I, *an.*).

When the auditory sac is cut open it is found to be full of sea-water, in which

* And perhaps also of smell.

are a number of little sandy particles, called ear-stones. or *otoliths*.

One more point about the structure of the organ. Underlying the whole hard shell of the lobster is a delicate red membrane. composed of minute protoplasmic

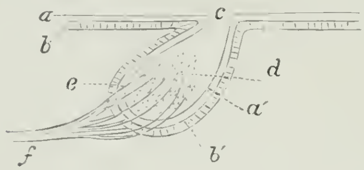


FIG. 2.—DIAGRAM OF AUDITORY SAC OF LOBSTER.

a, Shell of antennule ; a′, chitinous layer of auditory sac ; b, epidermis ; b′, epithelial layer of auditory sac ; c, mouth of sac ; d, otoliths ; e, auditory hairs ; f, auditory nerve.

bodies, and answering to our own epidermis. A similar membrane forms a sort of outer coat to the auditory sac, and is continuous around the aperture of the sac with the membrane underlying the hard shell of the antennule. just as the shell itself is continuous with the chitin of the sac.

To make out much more of the structure of the lobster's ear. it is necessary to have recourse to the microscope. If that portion of the wall of the sac containing the curved line is cut out and examined under a comparatively low power, a row of bodies called auditory hairs, or *setæ*, is seen to be attached all along the line, and to project into the cavity of the sac among the ear-stones. Each of these "setæ" is a beautiful feathery structure, consisting of a stem with a rounded base, which fits, ball-and-socket fashion, into a depression in the wall of the sac, and with a number of minute filaments corresponding with the barbs of the feathers, given off on either side. The whole seta is not more than $\frac{1}{60}$th of an inch in length. A specimen prepared with sufficient care shows that to each seta proceeds a minute branchlet of the auditory nerve (Figs. 2 and 3).

So much for the structure of the apparatus ; now for the way it acts. Sound waves from any sonorous body in the lobster's neighbourhood will strike against the bottom joint of the little feeler. Of these waves, those striking against the hard parts will have little or no effect unless the sounding body be in actual contact ; but those which strike the soft space already mentioned will set it vibrating, and the vibration, transmitted to the auditory sac, will produce a corresponding movement in its contained fluid. The same effect will be produced, but in a more marked degree, by waves entering the small external aperture. The movement of the fluid will cause the setæ to vibrate, and a nervous impulse will be transmitted along the auditory nerve, and so give rise in the brain to the sensation of hearing. The "otoliths" may assist in transmitting the vibration of the fluid to the hairs, or possibly may act as dampers.

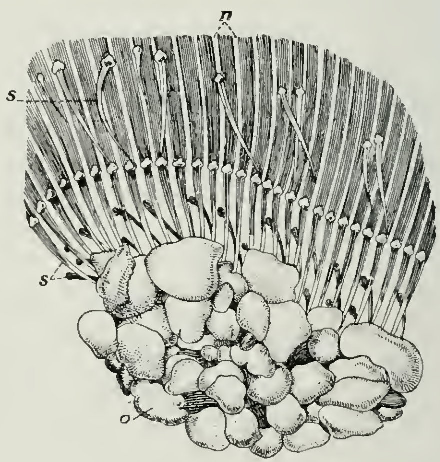


FIG. 3.—AUDITORY SAC OF LOBSTER, MUCH MAGNIFIED TO SHOW HAIRS AND OTOLITHS. (*After Hensen.*)

n, branchlets of nerve ; o, otoliths ; s, setæ.

There is still something to be said about the anatomical relations of the sac. It communicates with the exterior by a small hole, so that its wall is directly continuous with the outer surface of the body, and the whole sac might not unreasonably, from examination of it in the adult animal, be looked upon as a portion

of that outer surface tucked in. That this is really the case is found by examining lobsters of different ages, when it is seen that very young specimens have no auditory sac at all, and that when this organ does arise, it arises by the upper wall of the first joint of the antennule being pushed in, as it were, so as to form a shallow depression; this depression deepening, forms at last a bag widely open to the outer air, and lastly, the bag itself growing faster than its mouth, the auditory sac of the adult is produced.

Thus the wall of the sac is just a bit of the "shell," with its underlying epidermis, turned in; and the auditory hairs are nothing more than the hairs with which many parts of the lobster's body are covered—the tail, for instance, is fringed with them—specially modified for purposes of hearing, by acquiring great delicacy and by being very beautifully hinged.

There is no reason whatever why hairs on the free surface of the body should not have this same accurate adjustment, and so serve for hearing; and, indeed, it is thought by some competent authorities that certain fringed hairs on the surface of the antennules and of the tail of the prawn, closely resembling the hairs of its auditory sac, really do serve the purpose of hearing. If this be true, the prawn has some auditory hairs which have been tucked into a sac and others which have not. Of course, the former position must be the most suitable for the purpose, for in the first place the delicate hairs are protected from injury, and in the second place the sac itself probably acts as a resonator, and augments the force of the sound waves.

How, then, do the otoliths come about, since there are no representatives of them in connection with the hairs on the free surface of the body? I mentioned that these were sandy particles; they are, in fact, just minute sand grains, such as are found on the sea bottom where the lobster lives, and the question suggests itself, Are they actually formed by the lobster, or are they taken in from the outside? If so, how?

This question was settled in a very ingenious way by Dr. Hensen. It is known that lobsters and their allies—prawns, crabs, etc.—shed their shells annually, and that with the shell of the antennule the chitin of the auditory sac is shed too, and with it, of course, the otoliths, so that for a time after casting the shell the animal has a soft exterior, a soft auditory sac, and no otoliths.

Hensen took some prawns which had just shed their shells, and put them in an aquarium, the bottom of which was covered not with sand, but with some minute, easily recognisable crystals. In this way he made sure that the animals were not supplied with sand. He examined them after a short time, and found that they all had in the auditory sacs some of the crystals, which now acted as otoliths. They had taken them in by plunging their heads into the mass of crystals, and moving about until some of the latter were forced in.

Another form of auditory organ—at first sight quite different from that of the lobster—is found in the common little fresh-water bivalve called *Cyclas*. If this little creature is watched during life it is seen to protrude from between its valves a fleshy, tongue-like process, called its foot. If, now, a Cyclas is taken from the water, its valves removed, and its foot examined under the microscope, there is seen in about its middle a little rounded cavity containing a small particle in constant vibration. The cavity is the auditory sac of the Cyclas, and the vibrating particle is its otolith (Fig. 4).

Careful examination shows that this sac consists of a delicate wall lined with minute cylindrical cells, from each of which a number of delicate filaments,

called *cilia*, project into the cavity of the sac. These filaments are in constant motion, waving to and fro like the similar bodies in a wheel-animalcule, and it is by the motion thus set up that the otolith is kept in a perpetual tremble in the fluid which fills the sac.

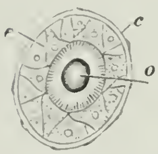


FIG. 4. — AUDITORY SAC OF CYCLAS.
(After Leydig.)
Cyclas is a little fresh-water bivalve.
c, auditory capsule; c, ciliated epithelium; o, otolith.

Comparing the auditory sac of *Cyclas* with that of the lobster, it is evident that the ciliated cells lining the former answer exactly to the cells of the epidermis forming the outer layer of the latter. But in *Cyclas* there is no chitinous inner coat to the sac, there are cilia instead of auditory hairs, and the sac is completely closed instead of opening to the exterior.

The last named circumstance seems to indicate a radical difference between the two organs, for it hardly seems likely, at first sight, that a closed sac embedded in the very substance of the foot can have any connection with the epidermis covering the foot. But there is every reason to believe that the sac in this case also arises as a pushing-in of the epidermis, a sort of tunnel being formed, the far end of which dilates into the sac, while the remainder of it disappears, all evidence of the original connection of the auditory sac with the exterior being thus obliterated. Here again, therefore, the sensory surface is a specially modified portion of the general surface of the body.

Another easily obtained auditory organ is that of any common bony fish, the cod, for instance (Fig. 5). Most people must have noticed a little white, flat stone with a crinkled edge, looking very like glazed porcelain, which occurs in the interior of a cod's head, apparently quite loose. This little stone is the ear-stone, or otolith, of the fish (Fig. 6). To make out its real position and relations, a dissection, or series of dissections, is necessary.

In the hinder part of the cod's skull, on each side of the brain case, is a large bony projection, containing an irregular cavity, in free communication, in the dry skull, with the cavity in which the brain is lodged. This bony mass is the auditory capsule. If, in a fresh head, the bone composing it is broken away bit by bit, the cavity is found to contain, floating in a watery fluid called *perilymph*, the fish's auditory organ, or, as it is often called from its complexity, *membranous labyrinth*.

This consists of a delicate membranous sac, of ovoid shape, called the *vestibule*, connected with which are three tubes bent into the form of a half-circle, and hence called *semicircular canals* (Fig. 5). Of these, two have a vertical position, one at the front, the other at the hinder end of the vestibule; the third is horizontal, and attached to the outer wall of the sac. The two vertical canals are joined with one another for a short distance, so that the two canals

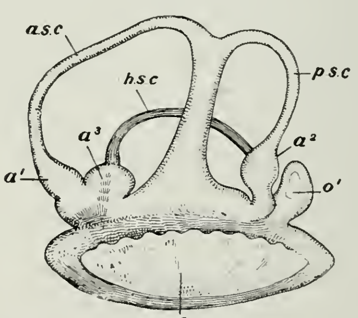


FIG. 5.—THE "EAR" OF THE COD.

a^1, a^2, a^3, ampullæ; a.s.c., anterior semicircular canal; p.s.c., posterior do. do.; h.s.c., horizontal do. do.; o, otolith; o^1, small otolith.

only have three openings between them into the vestibule; at the end farthest from its fellow each canal is swollen out into a little bulb, the *ampulla*. The horizontal canal is quite independent of the other two; like these, it has an ampulla placed at its anterior end.

The large otolith already mentioned lies within the vestibule, floating in the fluid (*endolymph*) with which that cavity is filled. Besides the large otolith there is another, of much smaller size, and therefore easily overlooked.

FIG. 6.—OTOLITH OF COD.

A large nerve (the auditory nerve) proceeds from the brain of the fish into the auditory capsule, and there branches out, twigs from it passing to the vestibule and to the ampullæ of the canals.

Microscopic examination shows that the membranous labyrinth has a lining of cells, resembling in all essential respects those we have already found in the lobster and *Cyclas*. In the ampulla and certain parts of the vestibule these cells give rise to long, stiff filaments, which project into the endolymph. The ends of the nerves split up into extremely fine branches, one of which, in all probability, becomes directly connected with each of the cells (Fig. 7).

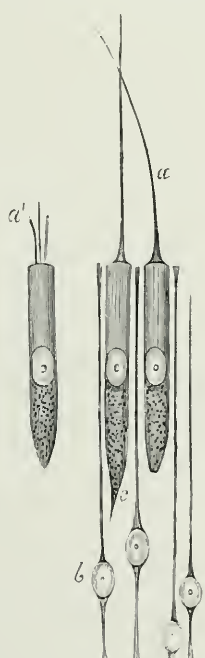


FIG. 7. — AUDITORY CELLS OF FISH.
a, a', auditory hairs; c, columnar cells; b, spindle-shaped cells lying between the columnar cells.

Hearing takes place in much the same way as in *Cyclas*: the sound-waves breaking against the fish's head are transmitted through the substance of the latter to the perilymph, thence to the labyrinth itself and its contained endolymph. The vibrations of the endolymph and of the otoliths affect the hair-like processes of the auditory cells; in these the vibrations are converted into a nervous impulse, which is conveyed along the auditory nerve to the brain, and there gives rise to the sensation of hearing.

Like the simple auditory sac of *Cyclas*, the fish's complicated hearing apparatus

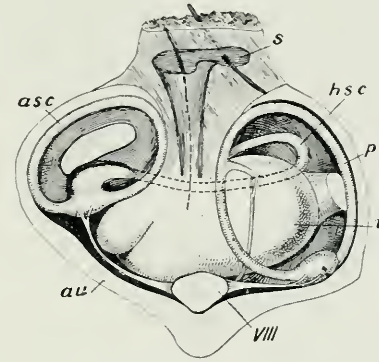


FIG. 8.—THE HEARING APPARATUS OF THE SKATE.
(*After Parker.*)
au, auditory capsule; a.s.c., anterior semicircular canal; h.s.c., horizontal do. do.; p.s.c., posterior do. do.; vb, vestibule; s, bristle; VIII, nerve.

is just an in-turned bit of skin. The auditory organ makes its first appearance as a little pit on the surface of the head; the pit deepens into a canal, the outer part of which becomes obliterated, while the inner is converted into the whole labyrinth. In some fishes, such as the shark, dogfish, and skate (Fig. 8), a fine tube—possibly representing the above-mentioned canal—is present throughout life, placing the cavity of the vestibule in communication with the surrounding water.

In the higher animals—in a sheep, a rabbit, a dog, or a man—the auditory organ has essentially the same structure as in the fish, in that it has a vestibule with three semicircular canals. But there is an important addition in the form of a long tube, blind at one end, and coiled up into a snail-shell-like figure of two and a half turns. This structure is called from its form the membranous *cochlea*. In all probability it has something to do with the appreciation of musical tones, though how it performs this function is by no means clear. Probably certain peculiar structures, called *hair-cells* and *rods of*

Corti, have something to do with it (Fig. 9).

Both labyrinth and cochlea contain endolymph. and are contained in a cavity

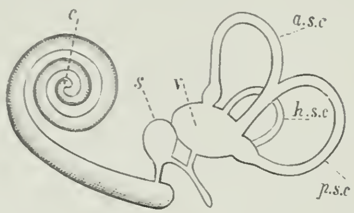


FIG. 9.—MEMBRANOUS LABYRINTH AND COCHLEA OF A MAMMAL.
(*After Waldeyer.*)
a.s.c., anterior semicircular canal; h.s.c., horizontal do. do.; p.s.c., posterior do. do.; v, vestibule; c, cochlea.

hollowed out in the auditory capsule. the cavity being filled, as before, with perilymph. But in this case the cavity is no longer irregular, but of almost exactly the same shape as the membranous organ it protects. Moreover, the bone immediately surrounding the cavity is of a particularly hard and ivory-like texture, while the next outer layer is full of cavities, and consequently comparatively soft. So that the surrounding soft bone can be cut away, leaving the hard bone immediately surrounding the labyrinth, and this hard bone is then found to have quite the same shape as the membranous organ. A *bony labyrinth* and *bony cochlea* are therefore often spoken of, in contradistinction to the membranous parts of the same name.

In the case of the labyrinth proper—vestibule and canals—the bony case fits pretty closely, and the perilymph-containing cavity between the bony walls and the membranous structures is very small. But the bony cochlea is of considerably greater diameter than the structure it contains, and the membranous cochlea is, as it were, jammed close against the surrounding bone on one side, so that on the other side a considerable space is left. This space is not single, but is divided into two compartments, an upper and a lower, by a bony partition, which stretches inwards from the wall of the osseous to that of the membranous cochlea. This partition is, like the cochlea itself, spiral, and consequently the whole cochlea, if cut across, is seen to consist of three separate passages running close alongside one another; a middle one, that of the membranous cochlea, containing endolymph, an upper, called the *scala vestibuli*, containing perilymph, and a lower, the *scala tympani*, also containing perilymph. The two latter communicate with one another at the apex of the spiral (Fig. 10).

I have hitherto spoken of the cavity in the bony apparatus as if it were completely closed in by bone all round, but this is not strictly true. At two places the bony wall is deficient, two little holes being present, which are covered over by very thin membranes. The larger of these is called, from its shape, the "oval window" (*fenestra ovalis*), the smaller the "round window" (*fenestra rotunda*).

The membranes which may be said to form the glazing of these windows separate the cavity of the bony labyrinth from a large and comparatively simple chamber, called the *tympanum*, or ear-drum. The bony wall containing the two windows forms the inner boundary of this drum-

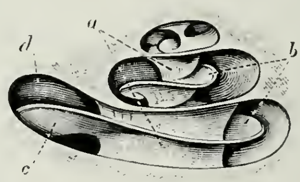


FIG. 10.—BONY COCHLEA, WITH PART OF ITS WALL REMOVED.
a, central pillar; b, spiral partition; c, scala tympani; d, scala vestibuli.

cavity; externally it is produced outwards into a canal, the external auditory passage, which opens on the side of the head, and is surrounded by the external ear. It is this canal which we see in our own "ear," leading somewhere into the interior of the head (Fig. 11).

There is a second canal in connection with the tympanum, called the *Eustachian tube*. It passes from the front part of the cavity, and passing forwards and downwards opens into the throat. So that if there were nothing else to be mentioned in connection with the tympanum, there would be free communication between the ear and the mouth.

But, as a matter of fact, there is no such communication. For, stretched across the inner end of the external auditory passage, just where it joins the drum-cavity, is a tough skin, the drum-membrane, which completely separates the cavity of the external passage from that of the drum.

Attached to the inner side of this membrane is a little bone, the shape of which is seen in Fig. 12 to bear some sort of resemblance to a hammer. It is hence called the hammer-bone (*malleus*); its "handle" is attached to the drum-membrane, its "slender process" projects into a cleft in the bone forming the wall of the drum, and its head is articulated or jointed to a second small bone, called the "anvil" (*incus*), rather from the fact that the head of the hammer is applied to it than from any resemblance it bears to an anvil. This anvil bone has, like the hammer, two projections or "processes," a long and a short; to the long process is articulated a tiny grain of bone, called the "orbicular bone" (*os orbiculare*), and to this again is jointed a bone which is very rightly called the "stirrup" (*stapes*), since it has precisely the shape of that article. The foot-plate of the stirrup is firmly fixed to the membrane of the oval window.

Now as to the use of all this complicated apparatus, which in the higher animals is superadded to the essential organ of hearing. The sound-waves enter the external auditory passage, some of them being reflected into it by the external ear, which acts as a natural ear-trumpet to catch the sound. Arrived at the bottom

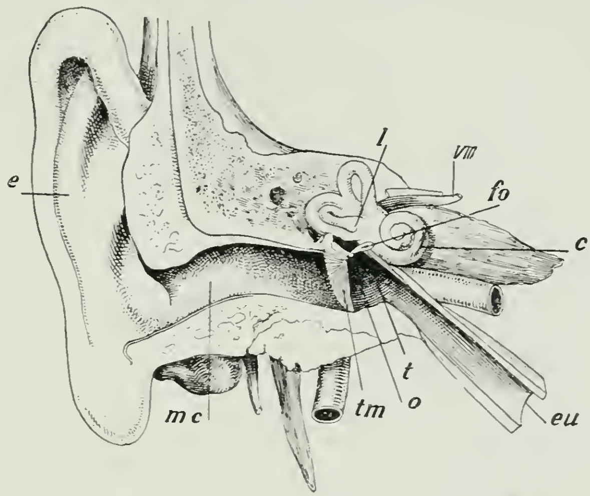


FIG. 11.—THE ENTIRE HEARING APPARATUS IN MAN. (COMPARE WITH FIGS. 5 AND 8.)

e, external ear; mc, external auditory passage; l, bony labyrinth; VIII, auditory nerve; c, bony cochlea; fo, fenestra ovalis; eu, Eustachian tube; t, tympanum; o, auditory ossicles; tm, tympanic membrane.

of the passage, the waves strike against the drum-membrane and set it vibrating: its vibrations give a corresponding backward and forward movement to the *malleus*, and the motion is communicated through the *incus* to the *stapes*, which, being fixed to the membrane of the "oval window," gives to the latter an in-and-out movement. This last movement, of course, affects the perilymph, and then everything takes place as in the codfish. The improvement in the mammal consists in the addition of a special delicately balanced apparatus to communicate external vibrations to the "perilymph." The round window serves for the vibrations of the perilymph to spend themselves against; every time that the oval window is thrust in the perilymph, instead of undergoing compression, it pushes out the membrane of the round window to some extent, and *vice versâ*.

A few words may not be amiss as to

the function of the little tube (the *Eustachian*) which has been mentioned as leading from the ear cavity down into the throat. If it were not for this tube the air within the ear cavity would be absolutely shut off from the outer air. Since the latter varies considerably in density with different states of the weather, the contained air might come to be either more or less dense than the outer, and the drum-membrane would thus tend to be forced either inwards or outwards by the inequality of pressure. It would consequently be unable to vibrate freely, and a certain degree of deafness would be the result. As a matter of fact, this does not unfrequently happen when the lining membrane of the throat is inflamed and swollen, the swelling spreading to the lining of the Eustachian tube, which thus becomes choked up. This is the reason why a "cold in the head" with sore throat so often causes a temporary deafness—sometimes even permanent deafness, unless the aid of the surgeon be invoked to open up and inflate the tube.

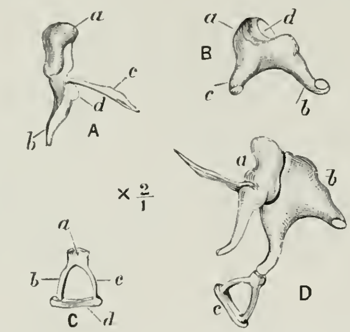


FIG. 12.—THE AUDITORY OSSICLES OF MAN (LEFT SIDE).

A, *malleus; a, head; b, handle; c, slender process; d, short process.*
B, *incus; a, the body; b, long process, with the orbicular bone attached at its end; c, short process; d, articular surface for head of malleus.*
C, *stapes; d, the base.*
D, *the foregoing in their natural connections, as seen from the outside: a, malleus; b, incus; c, stapes. (Twice natural size.)*

The above account of the organ of hearing aims at giving the reader some notion of the manner in which, and of the apparatus by which, the function of hearing is performed. I have purposely not attempted to go into details of structure, or into the endless modifications of the auditory organs in the various groups of animals, but have judged it best to select a limited number of common and easily obtainable animals, from the consideration of which the main types of auditory organs may be understood. Anyone with the least skill in dissection can make out at any rate most of the points described for himself, and those who are unable to do this can see preparations of the larger structures at any well equipped anatomical museum, such as those of the Universities, or that of the Royal College of Surgeons of England.

THE STAR-FISH AND ITS RELATIVES.

A STAR-FISH (Fig. 1) is one of the most "common objects of the sea-shore." A specimen is easily found, and when examined it will be seen to be one of the most remarkable creatures ordinarily familiar to us. Unlike a cray-fish or a frog, its mouth is not placed near one end of the body, but in the centre of its lower surface. We cannot speak of its right side and its left, but only of the rays or "arms" into which its central disc seems to be drawn out; while there are, again, no organs developed in it which we can compare in structure either to fins or to our own arms and legs.

When we look around among its immediate zoological relations we see clearly enough that the very same points are to be made out in them. If, for example, we take a brittle-star, or *Ophiurid*, we find five arms and a central disc. With the sea-egg, or *Echinus*,* a little more care is needed, for it does not have any outspreading rays, and the spines on the outer surface of the body are longer, and all the plates of the *test* or "shell" are firmer; yet we find five different sets of tubes ending in suckers, arranged in rows on its sides, which it is easy to compare with those underneath the arms of the star-fish itself. The further we get from this last the more do its particular characters seem to disappear. Witness the sausage-shaped sea-cucumber on the one hand, and the beautiful stalked sea-lily (*Pentacrinus*) on the other.

Notwithstanding all this diversity, these several forms may, by the leading points of their anatomical structure, be shown to be more closely allied to one another than to any other form now known to us. Let us take, step by step, the characters of the star-fish, and so see what these anatomical points are.

If we take for examination the common "five-finger" of our own coasts, *Asterias rubens* (Fig. 1), we find that we have to do with a flattened creature of a somewhat orange-yellow colour, in whose skin a number of calcareous bodies are to be felt by the fingers, and attached to some of which there is a number of short spines, many of them arranged in very regular rows. When we look at the under surface, which is very much whiter than the upper, we see that from the central mouth there spread out five grooves, in which there are placed a very large number of tubes ending in suckers, and these are, with a little care, seen to be set in what appear to be cross rows of four. The arm gradually diminishes in width on its way to the tip, where it is a little bent up and provided with a special organ, which we shall soon find out to be an eye. The tubes are soft, and pass out between the solid joints which go to make up the principal portion of the skeleton of the arm, and are the chief means of progression. The apparatus by which this is effected is very curious and somewhat complicated, but it is to be regarded as a very complete piece of work, as the following account will show.

Connected with the tubes is a canal system, the "pipes" of which are known as the "water vessels." They are connected together by a ring round the mouth, and this ring has its more special communication with the outer world by means of the so-called "stone canal," that opens on the upper side of the body

* These creatures are often called sea-urchins; but "urchin" is only a modified form of the French for hedgehog (*oursin*).

close to the junction of two arms with one another. Branches pass out from the circular vessel, and run down the groove of the arms to communicate with the "tube-feet" and with a small swelling (Fig. 2, *a*) which is set at the base of each of these. These swellings are capable of contraction, and they, by driving out the water that has passed into them from the common connecting-tube, are enabled to fill the "tube-feet" and so drive the sea-water along the canals and so into the feet.

Whence comes this sea-water? Through the stone canal, of course, which it freely enters through tiny holes in the "*madreporic plate*," which lies across its outer end. I shall explain later on the history of this curious arrangement, and will now only say that there are deposited in its walls, just as there are deposited in several portions of the star-

FIG. I.—THE COMMON FIVE-FINGERS (*ASTERIAS RUBENS*).

fish's body, a number of small, hard bodies, which are, like the skeleton and spines of which we have already spoken, principally made up of carbonate of lime.

to bring them into a firmer condition. Just as each foot has its own special swelling (which is known technically as an *ampulla*), so, too, there are special swellings in the central portion of the water-system. These are set between each radiating canal, and are named *Polian vesicles*, in honour of the Italian naturalist, Poli; like the more special ampullæ, they are provided with muscles in their walls, and their contraction, aided by the delicate processes which line the walls of the canal tubes, is sufficient to

The sucker-feet and their connecting canals are not, however, all that is to be found in the groove of the arm (Fig. 4). If we carefully separate the suckers on one side from those of the other, we shall find that there is a delicate band running over the water-canal, and we shall, on dissection, find that this band may be traced into a circular ring of whitish substance,

which, like the canal-system, runs round the whole of the disc, and connects with one another the double series of cords (for double they really are) which belong to

FIG. 2.—THE WATER-VESSEL SYSTEM OF THE STAR-FISH.
(*Modified from Lang.*)
a, ampulla; b, blood-vessel; br, bronchial vesicle; T, tube-feet; s, sucker; w, water-vessel; sp, spine; i, intestine.

each arm. This is the *nervous system* of the star-fish, and there are lessons to be learnt from it which have a very wide and general bearing. It is commonly said that "Touch is the mother of all the senses." Now the real meaning of this aphorism lies in the following facts. At a very early period in its history nearly every animal consists of two layers: from the outer one, which is technically known as the "*epiblast*," swellings are developed, which gradually take a deeper position in the body, and go to form the chief part of the nervous system. Without a knowledge of the history of the chick, for example, it would hardly ever be imagined that the greater part of the "spinal cord" of the fowl had arisen from the same layer of cells as that which had given rise to the outer skin. Such, however, is the fact, and the importance of a knowledge of the arrangements of the nervous system in the star-fish is due to the close connection which still obtains in this form between the investing skin and the underlying nervous cords. In other animals similar relations are to be found, and while we cannot and must not deny that it is to the study of development that we owe our knowledge of the origin of the nervous system, we may very properly draw attention to the support which is afforded to its teachings by the observations of comparative anatomists. And here, again, we have another example of the truth on which the great philosopher and naturalist insisted when, in words that have been thus translated, he taught us that:—

> All forms have a resemblance, none is the same as another;
> And their chorus complete points to a mystical law." *

While applying this teaching to practice, we may say that he who would fully understand the structure and relations of animals must always look upon the study of developing and of developed forms as the two sides from which it is necessary to carefully examine every living creature.

We have not yet, however, done with all the organs of the body which make their way into the arms (Fig. 4). The digestive tract sends up on each side a long, dark tube, which has many sacs; and at the base we find a duct which leads from glands of shorter length in which we find the sperm, or the eggs, developed. Before passing to the digestive system, let us say just a word as to that special organ at the tip of the arm which we have already asserted to be an eye. This tip is generally bent up, thanks to a muscle which runs along the back of the arm under the skin, and it is thus more completely exposed to the light. It is provided with about a hundred spots, more or less distinctly coloured red by pigment, and surrounded by cells which are rod-shaped, and enclose among them a trans-

* "Alle Gestalten sind ähnlich, und Keine gleichet der andern;
Und so deutet der Chor auf ein geheimes Gesetz."
—*Goethe.*

parent body. The whole arrangement is placed on a swelling of the nerve cord, and nerve fibres have been observed to pass to it.*

There are no special hard structures in the way of teeth in the star-fish itself, and the opening of the mouth is pretty wide. The end of the intestine opens on the other side of the disc, not far from the centre of it, by a small and inconspicuous orifice. The tract is very simple, and the only point of importance which we need note with regard to it is the outpushing of its parts into the several arms.

Coming now to the hard parts which make up the skeleton, we have to commence by drawing attention to one or two important considerations. It is obvious that that part of the body which is connected with the suckers may be sharply marked off from the parts that have no direct relation with these tubes. This matter is not very easily made out in the star-fish, but is exceedingly well marked in its close zoological relation, the sea-urchin; and we will, therefore, anticipate matters a little by describing the shell—or, more properly speaking, the *test*—of this animal (Fig. 3). Examining this carefully, and taking no note for the moment of the plates at the pole opposite to the mouth, but looking only at the series of plates which are in relation with the general surface of the body and go to form its "corona," we see that it is divisible into five similar regions, that each of these regions consists of four rows of plates, and that of these rows one pair is perforated by a number of small pores, while the plates of the other row are larger (though that is a matter of no importance) and are not perforated at all. The former series or rows of perforated plates are known to zoologists as the "*ambulacral plates*," while the others are, from their position, known as "*inter-ambulacral plates*"—that is, plates which are unperforated, and between the rows of those pierced by the suckers. So much is clear and easy; and we can now see, by an examination of Fig. 3, that, on each side of the groove in which the suckers are placed, there is a single plate which carries no spines, and that on each side of this there are several plates which do carry spines. When we look more closely we find that those plates which do not bear spines have very much the same relation to the suckers as have the "ambulacral" plates of the sea-urchin, and that they only differ from them in the fact that the suckers pass out between them

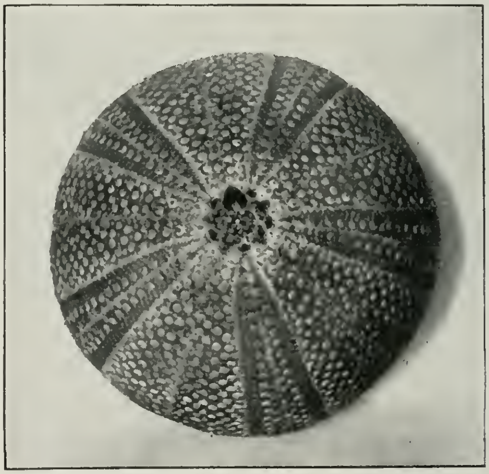


FIG. 3.—TEST, OR "SHELL" OF A REGULAR SEA-URCHIN (*ECHINUS ESCULENTUS*).

instead of passing through them. Similarly, the spine-bearing plates are those of the unperforated series; and we have, therefore, in making any exact examination of the skeleton of the star-fish, to distinguish between the *perforated* and the *unperforated* plates. The spines on these

* The genial and accomplished Edward Forbes gives an account of his adventures with a peculiarly fragile star-fish (*Luidia*, so named in honour of Edward Lhywd), which I cannot refrain from quoting:—"Whether the cold air was too much for him, or the sight of the bucket too terrific, I know not; but in a moment he proceeded to dissolve his corporation, and at every mesh of the dredge his fragments were seen escaping. In despair, I grasped at the largest, and brought up the extremity of an arm with its terminating eye, the spinous eyelid of which opened and closed with something exceedingly like a wink of derision."—Forbes, "British Star-fishes," p. 139.

plates are never very long in the star-fish, and it is needless to say very much as to their structure. The most remarkable point about them is the fact that some of them, instead of growing into more or less solid rods of carbonate of lime, become divided at their extremity, and thus form the two or three snapping processes which are hinged on to the end of the modified spine, and are to be seen in active movement in a living star-fish, twisting about and, by the aid of muscles, seizing upon whatever is minute enough to come in their way. These bodies were long ago observed, and were for a considerable time thought to be independent animals living as parasites upon the surface of the creature; and it was for this reason that they had applied to them the not very elegant term of *pedicellaria*. This name they still retain. Small and comparatively inconspicuous as the spines are in the star-fish, they are often of great size in the sea-urchins, and form, it may be, club-like or cigar-like spines, sometimes elegantly banded, or, as in the "Piper," they may be more delicate though still strong, and may well be compared to stilts, in length very much surpassing the longest diameter of the body.

The respiratory arrangements are most delightfully simple. We can easily imagine that when a creature is very small, and has a very thin body wall, the fresh oxygen which it requires may be gained for it by mere exchange through this body wall, and, when we find such a process, we say of the creature that "its respiration is vague." Well, the star-fish has adopted a method of respiration which is hardly anything of an advance upon this. Owing to the fact that it has not a continuous skeletal covering, as has the sea-urchin, there are left in its body wall a number of thinner spaces interspersed in the calcareous network, and through these the creature protrudes a portion of the lining wall of its body cavity (*br*, Fig. 2), which is thin and membranous. In the body cavity there is a quantity of fluid which is driven about by the delicate processes, or cilia, developed in its lining wall, and the fluid is thus brought into very close relation with the sea-water in which the star-fish lives. It is probable, too, that the fresh sea-water which comes in by the stone canal is in some way able to pass into the body cavity, and so to mix with the nourishing fluid there contained. From this fresh sea-water, whether thus introduced or that surrounding the animal, the nutrient fluid gets what is a most important part of the nourishment of every living organism—a fresh supply of oxygen.

Of the blood-vessel system we may say at once that there is considerable difficulty in finding a true heart or contracting organ which will drive the blood through the body. As to the rest, a blood-vessel appears to run along each arm (Fig. 2, *b*), in company with the nerve cord, whose course we have already described. Just as the nerve cords and the canals or "pipes" of the water-vessel system are connected with each other by a circular piece which runs around the disc, so, too, is there a circular blood-vessel running round the mouth. There are other vessels also, which we need not describe; but we shall, before we have done, see what is the possible meaning of this circular blood-vessel surrounding the star-fish's mouth.

We have now made out the leading characters of the anatomy of a star-fish, and we have seen enough, at any rate, to show us that in some important points this creature and its allies differ very markedly from all other forms. Henceforward we shall be disposed, first of all, to agree with those zoologists—and in this point the zoologists are nearly agreed among themselves—who separate off the group to which the object of our study

belongs from all other animals. To this group there has been applied the name of *Echinodermata*, from the characters of their integument (*echinos*, a spine; *derma*, skin).

The illustrious Cuvier was struck by the fact that the group did not exhibit an equal development of right and left sides—that, in fine, the Echinodermata were not *two-sidedly* symmetrical. He saw that in their adult condition—and the earlier or larval stages were not known to him—the parts of the body were equally disposed along rays or radiating lines—that, in fact, they were *radially* symmetrical; and he proposed therefore to associate them, under the great head of the *Radiata*, with such animals as the sea-anemone and the coral-making animals, which, with the sea-jellies, also exhibit a rayed symmetry. For a long time this division of the animal kingdom was regarded by naturalists as a natural and just one, and it was not till the year 1848 that it was successfully attacked. Earlier than this, indeed, a small portion of the group had been cut off from it, and associated with another great division; but it was not till the two German naturalists Frey and Leuckart demonstrated that the sea-jellies, corals, and so on, differed from the rest of the Radiata by the characters of their digestive tract, that the death-blow was really given to this classification. At the same time, these naturalists insisted on the fact that the Echinodermata had their closest alliance with some of the worms, in which two-sided symmetry is very evident.

We have, then, two views as to the relationships of the star-fishes—one, that the star-fishes are really allies of the sea-jellies, sea-anemones, corals, etc.; the other, which is held by the majority of naturalists, that their closest affinities are with the worms. As we shall shortly see, there are two lines of argument by which this may be supported—the one is the striking resemblance that there is between some worms and some of the sausage-shaped sea-cucumbers, and the other is the remarkable course of develop-

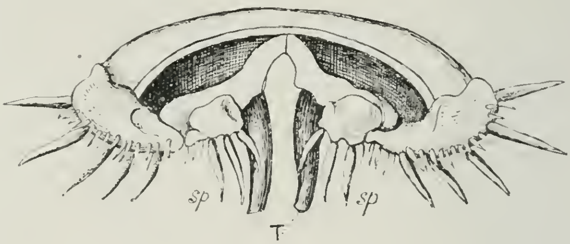


FIG. 4.—ARM OF A STAR-FISH CUT ACROSS.
sp, sp, spines; T, foot.

ment through which the young star-fish passes. In a larval stage it swims about freely, and exhibits a completely marked two-sided symmetry.

That we may, however, have the whole case before us, it remains still to mention a third view as to the history and origin of these interesting and difficult forms. It was put forward by the eminent naturalist Haeckel, and maintained, that the star-fish is really a colony of several worm-like creatures, which have joined themselves together by a common mouth and disc. This view of the "colonial" character of the echinoderm is, with his accustomed vigour, stated by the German naturalist to be the sole theory which attempts "the genetic explanation of this remarkable group of animals." It is impossible to deny that there is much in the structure of the arm of a common star-fish which supports the view of Professor Haeckel. There are, of course, a number of difficulties which stand in the way, and attention is directed to them for the purpose of illustrating how even in the details, dry as they must often seem, of the facts of anatomical structure it is possible to deduce, by the aid of a skilfully cultivated imagination, explanations which, even if

they do not explain all that seems to need explaining, do yet throw on the facts themselves a bright and instructive light.

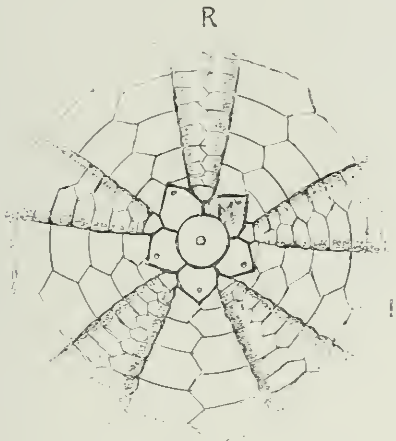


FIG. 5.—APICAL PLATES OF A REGULAR SEA-URCHIN AS SEEN FROM ABOVE.
(Modified from Claus.)
R, ray; I, inter-ray; M, madreporic plate.

Even here, however, we find true the words of the wise man of old, that there is no new thing under the sun; and it may be of interest to recall to the memory of the objectors that so long ago as the year 1837 the French naturalist Duvernoy spoke of the star-fishes as "serpents with many bodies, but one mouth."

It is now advisable to sketch briefly those series of changes during which the two-sidedly symmetrical larva is converted into the five-rayed star-fish; for this purpose, however, it is necessary that we should commence with an account of a somewhat simpler history than that which must be given of the type we have chosen. Let us begin, therefore, with one of the sea-cucumbers, or *holothurians*—those curious sausage-shaped creatures which it is not always easy to distinguish from some worms. When the egg of these creatures has passed through a series of changes which are, on the whole, common to it and all other eggs, it appears as a somewhat elongated or oval body, which is at first richly provided with those delicate processes which are ordinarily known as *cilia* or lashes. These cilia become confined to a special band (Fig. 6), and the larva is seen to be provided with a "digestive tract." From this a vesicle is constricted off, which divides again, and the upper part gives rise to the stone canal. As these two parts grow they become connected with the body wall, and during their growth there is gradually formed in the middle of each mass of cells a cavity. It is this cavity which forms the space which we learn to regard in the adult as the *body cavity*. About this time a mouth breaks through the wall of the body into the digestive tract. The larva gradually becomes barrel-shaped, and tentacles begin to appear. The sea-cucumber gradually takes on the definite form of the adult, no part of the larva, however, being cast away.

In the ordinary history of the star-fish a large part of the body of the larva never comes to take any share at all in the formation of the organs of the adult, and as this complicates matters a little, we

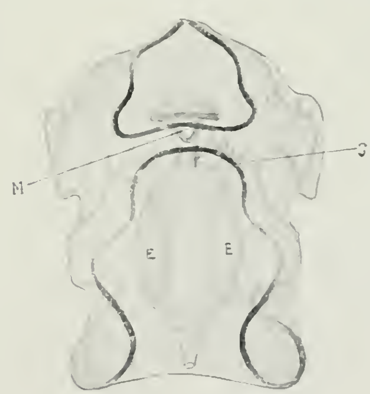


FIG. 6.—AURICULARIA LARVA OF A SEA-CUCUMBER.
(After Lemon.)
M, mouth; S, stone canal; E, sacs that give rise to the body cavity.

have preferred to start with an easier case. We have, however, learnt, or at least read, so much about the star-fish itself that it is necessary for us to give

a little attention to its earlier stages. Here we find on each side of the stomach an enlargement is apparent, which gradu-

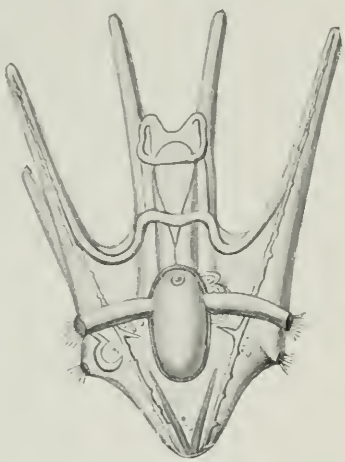


FIG. 7.—LARVA OF A SEA-URCHIN (*ECHINUS LIVIDUS*). (*After Metschnikoff.*)

ally grows out and goes chiefly to form the two walls of the body cavity. One of the outgrowths becomes also connected with the outer surface of the body, and the connecting tube is, as we might suppose, the future stone canal. Five little bulgings soon appear, which are to become the pipes which go to arms of the future star-fish. The processes grow and grow, and finally surround part of the intestine. It is not, however, the more anterior portion that they surround, and so it happens that the anterior part becomes cut off and gradually lost, while a new mouth is developed between these two processes, which, besides forming the body wall, do, of course, give rise to the water-vascular canals and the ambulacral feet. With the old mouth and gullet other parts of the original larva also disappear, and so it happens that in the star-fish it is not all, but only a part, of the larva which passes into the substance of the adult.

On this occasion we have no space to go into the various forms which the free-swimming larva may take on, for these are very various, and appear in many cases to be very complicated. In the sea-urchins and in the brittle-stars (Fig. 7) the sides of the body become drawn out into long processes, and the whole creature becomes absurdly like a painter's easel, for the arms are supported by rods of carbonate of lime which are developed in them. It is, however, necessary to say a very few words as to the larval form of the Rosy Feather-star, *Comatula* (Fig. 9), because it displays in an especially remarkable way the intimate relation which subsists between the development of an individual in the present and of a race in the past. This *Comatula* is one of the last survivors of a group which in the earlier ages of the world was abundantly well represented by a number of the stalked Lily Encrinites. In some rocks these encrinites are exceedingly common, and poetry and peasant lore have woven around them some strange tales, such as

FIG. 8.—BARREL-SHAPED PUPA OF A SEA-CUCUMBER.
(*After Lemon.*)
t, *tentacles*.

that one which Sir Walter Scott refers to in a familiar passage in "Marmion" ii. 16.

In the adult stage this feather-star cannot be said to be very like "St. Cuthbert's

beads," for it has not the jointed stalk of its ancient allies, some of which are still found living here and there on the world's surface; but it is very striking to note that, during development, this feather-star of our own seas does pass through a stage in which a stalk is attached to the round, disc-like body of the young, on the side which is opposite to that which carries the mouth.

We have now seen that the "radial symmetry" of the star-fish is something which is, as it were, secondary. A study of its development gives no support at all to the doctrine that the star-fish is a radiate animal like the sea-jelly, and, though we find in it some superficial resemblances, we have here only an illustration of the wonderful effect which community of habit or of home has on the most diversely arranged organisms; and while we are taught to admire the adhesion to ancestral arrangements which is exhibited by every group of animals, we learn at the same time that, underlying them all, there is some general disposition which compels them to fight their battle for existence with very much the same weapons and in very much the same way.

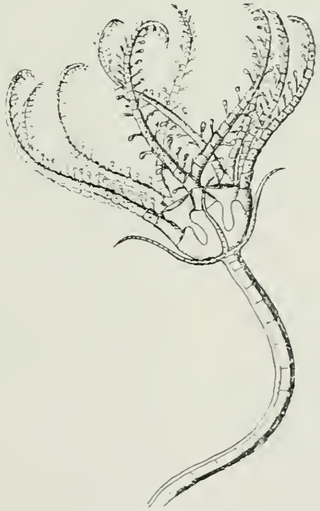


FIG. 9.—A DEVELOPING *COMATULA*.

FIG. I.—TYPICAL SAHARAN LANDSCAPE.
From a photograph by Dr. Gerhard Rohlfs.

EARTH'S TREELESS REGIONS.

THE earth's surface presents for our study and observation a truly wonderful variety of form and character. In the first place, we find, as we travel over it, that we have to accustom ourselves to great changes of temperature, the range—as measured by the Fahrenheit thermometer—to which the traveller may be exposed, between the burning sands of the Desert of Sahara and the regions of the frozen north, being as much as 200 degrees. Even upon the same spot it may, with the seasons, vary fully three-fourths of that amount. The most rapid change of climate may, however, be made by rising or descending in altitude. A few hours' climb will carry the traveller from a tropical heat to eternal snow and ice. The change from a very moist to an exceedingly dry climate is another familiar experience of every person who has given a moderately wide range to his journeyings.

Diversity of surface is another and an important element in the sum total of impressions made upon the mind as any

AN OASIS IN THE DESERT.

THESE FERTILE SPOTS, WHOSE CHIEF VEGETATION (IN THE SAHARA) CONSISTS OF DATE AND DOUM PALMS, ARE FOUND WHEREVER THERE IS WATER NEAR THE SURFACE. WELLS ARE DUG, AND THUS THE OASIS BECOMES A NATURAL STOPPING PLACE FOR CARAVANS. FRENCH ENTERPRISE HAS CREATED OASES IN SEVERAL PARTS OF THE ALGERIAN DESERTS BY CAUSING ARTESIAN WELLS TO BE SUNK.

particular region of country is looked upon by even the least reflective traveller. The manifold varieties of form which exhibit themselves in plain, valley, gorge, cliff, and precipice make up one of the essential elements of what we call the landscape.

The form of the surface depends chiefly on the character of the underlying rocks, and the diversities of condition to which these have been subjected during the lapse of the geological periods. Rocks, however, both in form and character, repeat themselves all over the world. The most skilful geologist could not, if dropped at random anywhere on the earth's surface, place himself, or make out approximately in what region he was, from an examination of the rocks alone. If these, however, contained fossils, he might in many cases be essentially aided in his endeavour to ascertain his whereabouts by their study; for although there is a wonderful resemblance in not a few instances between the extinct fauna of different regions, this resemblance rarely amounts to identity. Moreover, such an investigation of the fossil forms of any district necessarily presupposes search beneath the surface, while our object at the present time is only to consider what is above it.

The flora of any region is, or might be, to the botanist who was thoroughly familiar with the vegetation of the entire earth, almost an infallible guide in such a case as has here been presupposed. We might imagine a person to have made himself so well acquainted, by study in the herbarium alone, with the different plants growing over the earth's surface, that he would, in a general way, if set down anywhere on it, give a very good guess as to his whereabouts. No geologist, however, would succeed in doing this, or in making any approach to it, from a study of the rocks alone, no matter how minute his preparatory studies might have been. Nor would the simple topographer fare better in this respect, for surface forms and contours repeat themselves indefinitely; and although it is true that in no two places are they exactly alike, yet there is no such method and harmony in the grouping of topographic details that any particular form could be assigned to any particular region. The inference from this is, that however important form of surface may be, as giving character to the scenery, yet the vegetation with which that surface is clothed is really the most essential feature in the landscape.

It is of one particular form of surface, and of the vegetation which is more or less peculiar to that form, to which the reader's attention is to be called at the present time. The more nearly level portions of the earth, and the kind of flora which these exhibit in various countries, are to be studied for the purpose of finding where they are situated, what has been their origin, and how their topographical features and climatological conditions are connected, in a general way, with the character of the vegetation with which they are clothed.

We have not far to look before discovering that comparatively level regions, distinguished by peculiarities of vegetable growth, are of common and widespread occurrence over the various landmasses of the earth. It appears also that a number of terms designating these peculiar areas are in general use, and that there is no sharp line to be drawn between them. To a certain extent, however, we do use, in speaking of these level areas, the same term which the people themselves employ who live in the region we mean to designate. Thus we speak of the *steppes* of Asia, the *tundras* of Siberia (Fig. 2), the *pampas* of Central South America, or the *llanos* of the Orinoco, because the inhabitants of those regions themselves use those words as indicating the peculiar features of the surface in question. Yet some

of these terms, especially the word *steppe*, which is the German modification of the Russian word *step*,* is frequently applied to other regions than that of Northern and Western Asia, where it properly belongs. Thus we often read in works of physical geography of the steppes of Russia and Central Asia the grass-covered plains of the lower regions and the almost entirely barren valleys lying between the various mountain ranges which are piled up over so large a portion of High Asia. Absence of trees is the essential feature in both the "steppe"

Photo: J. Foster Fraser, Esq.

FIG. 2.—LIFE IN SIBERIA.

and the "high steppe," as these regions have been and may perhaps with propriety be designated. The lower regions are in large part well covered with grass and wild flowers in spring, and are suitable for occupation by a pastoral people, dependent chiefly for the means of sustenance on their flocks and herds, but in winter they are dreary, snow-covered wastes. The higher valleys are almost uninhabitable, very sparsely covered with a shrubby vegetation, and both too cold and too dry to offer any attractions except to the adventurous geographical explorer, who has still much to accomplish on the great central plateau of High Asia before its topography and natural history are satisfactorily made out, even in their most general features. The saline

Western North America, while some of the terms which belong to this category are applied quite vaguely, and somewhat differently, by various writers.

We may begin our studies with the steppes of Asia, since these are the grandest of all in extent, and perhaps the most varied in character; for not only are the vast areas of that nearly level and treeless country—which lie along the northern and north-western side of all the great central elevated mass of that continent — commonly designated as steppe lands, but a large part of that central region itself is described under that name by recent eminent geographical authorities, so that we may include in the various forms of steppe existing in

* German, *die Steppe*.

steppes in the neighbourhood of the Caspian are deserts in the truest sense of the word, and a more inhospitable region could scarcely be imagined.

The vastness of the area which may be designated as steppe on the Asiatic continent is almost overwhelming. Nearly half of the 18,000,000 square miles which Asia covers is essentially a treeless region, and perhaps a half of that half belongs to the high steppe division, in which cold and dryness are the predominant characteristics.

In North America, where the treeless regions occupy so large an area, and where many of the physical conditions closely resemble those prevailing on the Asiatic continent, the use of the term steppe has never been introduced among the people. Here, in fact, the character of the surface and distribution of vegetation over it, as well as its climatological peculiarities, have all been more satisfactorily and fully made out than in Asia, in spite of the fact that the latter country has been so much longer an object of scientific study. We may therefore dwell more at length on the treeless regions of the Amercian continent than we have done on those of the Old World.

As in the case of the Asiatic High Plateau (Fig. 3), so in North America we have an elevated region of great extent, intersected by numerous mountain ranges rising much above the general level of the plateau itself. In Asia this high region is centrally situated with reference to the continental mass; but in North America it occupies the western side of the continent, and on the Pacific side descends suddenly and rapidly to the ocean level. In approaching this high, mountainous division of the continent from the east, the traveller passes over a surface which appears to the eye to be almost everywhere level and unbroken, but which really rises with a very gentle but gradually increasing slope to the base of the Rocky Mountains, where the elevation is nearly a mile above the sea-level. This gently sloping belt has a width of more than five hundred miles, and extends from Mexico north through the whole continent to the Arctic Ocean. It forms the region universally known in the United States as "The Plains." It is an area nearly destitute of trees, but covered with a growth of various grasses, dense and abundant in the lower regions, and gradually becoming

FIG. 3.—A CHEERLESS PROSPECT: A THIBETAN DESERT.

less so as we rise in altitude, but nowhere absent altogether. Trees, chiefly of the poplar family and familiarly known as "cottonwoods," are hardly found at all, except along the edges of the streams, and they become less and less abundant as we proceed westward. This is the region once thronged by vast herds of "buffalo" (*Bison americanus*), now only represented by a few "preserved" herds, such as those in the Yellowstone Park.

Photo: Detroit Photographic Co.

FIG. 4.—ACROSS THE DESERT NEAR BAGDAD.

Beyond the Rocky Mountains, and between that range and the Sierra Nevada, is a belt of country in the central part of the territory of the United States which is more than a thousand miles in width, a large portion of which is without drainage to the sea, and is known as "The Great Basin." From the predominance over much of its surface of a shrubby plant familiarly called "sage-brush"—a species of *Artemisia*—the region is frequently designated by its inhabitants as "the sage-brush country." The valleys of the Great Basin are not suited for pasturage, except to a very limited extent. "Bunch-grasses,"* of which *Poa tenuifolia* is one of the most abundant and valuable, are sparsely scattered over the lower hill-sides, and along the river banks there is often a coarse growth of sedges, with a few cottonwoods and shrubby willows. The sage-brush country, as it continues to the south-west towards Mexican territory, becomes more and more occupied with various forms of the *Cactus* family, some of which have the proportions of trees, and give rise to the most curious type of landscape (Fig. 5).

Between the Rocky Mountains and the Great Basin there is, included within the parallels of 36° and 44° and lying chiefly in the states or territories of Colorado, Wyoming, and Utah, a broad belt of country greatly diversified by mountain ranges, and very dry and

* This term is applied to many grasses. The species noted in British Columbia and the neighbouring parts of Washington territory for its fattening qualities is *Elymus condensatus*, Presl.

forbidding, although having a drainage to the sea. A large part of this region is underlain by fresh-water Tertiary deposits, and belongs to the type of country known throughout the Far West as the "Mauvaises Terres," or "Bad Lands." The typical Bad Lands are, however, on the eastern side of the Rocky Mountains, and are largely developed along the various branches running into the Missouri River from the southwest, within the limits of the territory of Dakota. The Tertiary rocks of the Bad Lands are soft and permeable to water, and, being very easily eroded away, they have been worn into forms of the most striking and even picturesque character, although the general aspect of these regions is one of utter sterility, a condition resulting partly from the nature of the rock formations, and partly from the general extreme dryness of the climate.

Immediately upon the very backbone of the country, within the area occupied by the ranges properly designated as the Rocky Mountains, there are several broad and nearly level tracts, formerly the beds of lakes, which have become dry during later Tertiary times, and which are almost entirely destitute of arboreal vegetation. These areas have been long known as "The Parks," a name peculiar to this region, and which seems to have had its origin in the fancy of the early hunters, by whom also the smaller treeless plains, scattered here and there through the mountains, were designated as "Holes."

Between the sage-brush covered valleys of the Great Basin rise numerous ranges of mountains, on the summits of which snow is usually to be found through the whole summer, lying in small patches in sheltered gorges, near the very highest points. None of these ranges rises high enough to have what may be properly called a line of perpetual snow. The lower slopes of these mountains are usually quite destitute of trees, which, however, make their appearance on the higher ranges as we rise toward their summits, the juniper and the one-leaved pine being the predominating species. The whole aspect of the vegetation, both of mountain and valley, is extremely monotonous, while the topographic features of the country are varied, and even attractive, from the brilliancy and beauty of the atmospheric effects, which are connected in their origin with the prevailing dryness, and which, at certain times, especially at sunrise and sunset, seem almost to glorify a region otherwise repellent in character.

Next to Asia and North America the southern division of the New World demands our attention for the great extent of its level and treeless areas, so well known from the picturesque descriptions given by Humboldt.

The treeless areas of that country are known by various names. They are called *llanos* in the regions north of the equator, where they lie chiefly within the limits of Venezuela; in Brazil they are designated as *campos*, and as *pampas* in Peru, and especially in the central region lying between Brazil and Patagonia, and mostly included within the territory of the Argentine Confederation. The Spanish word *llanos* is almost exactly the equivalent of the English "plain," the idea of flatness being the predominant one in both cases. "Campo" is the equivalent of the Latin "campus." But "pampa" appears to be a word which originated in some one of the South American aboriginal languages. It is applied in Peru to the regions of moving sand dunes along the coast, but not to the treeless slopes of the Andes.

The "llanos" of South America are described by Humboldt as extending from the Caracas coast chain to the forests of Guiana, and from the snowy mountains of Merida to the great delta formed by

the Orinoco at its mouth, embracing an area of a quarter of a million square miles. According to official determination, nearly two-thirds of Venezuela is "llano," or grassy plain, the prevailing vegetation belonging to the two orders of *Cyperaceæ* and *Gramineæ*. A large part of the surface is described by Humboldt, as well as by Codazzi, by whom it was officially surveyed for the Government, as being extraordinarily flat—so much so, indeed, that over areas of several hundred square miles "no part seems to be a foot higher than the rest." The region of the llanos is one of large rainfall, but the precipitation is very irregularly distributed through the year, being entirely confined to the so-called rainy season. Humboldt describes with poetic fervour the awakening of the vegetation to renewed life under the influence of the welcome rain.

The pampas occupy a much larger area than the llanos, and are, as stated by recent travellers, of a considerably diversified character. The whole region commonly included within the designation of pampa by physical geographers extends over more than a million of square miles. Some of this is grassy plain, well fitted for pastoral uses; a portion farther to the north, where dryness is a more predominant characteristic, is a barren waste, the soil being thoroughly impregnated with saline matter, evidently the bed of one or more former lakes. Flatness, absence of trees, abundant development of grasses in the moister portions, these are the characteristics of the region of the pampas, just as we have seen that they are of the steppe and the plains.

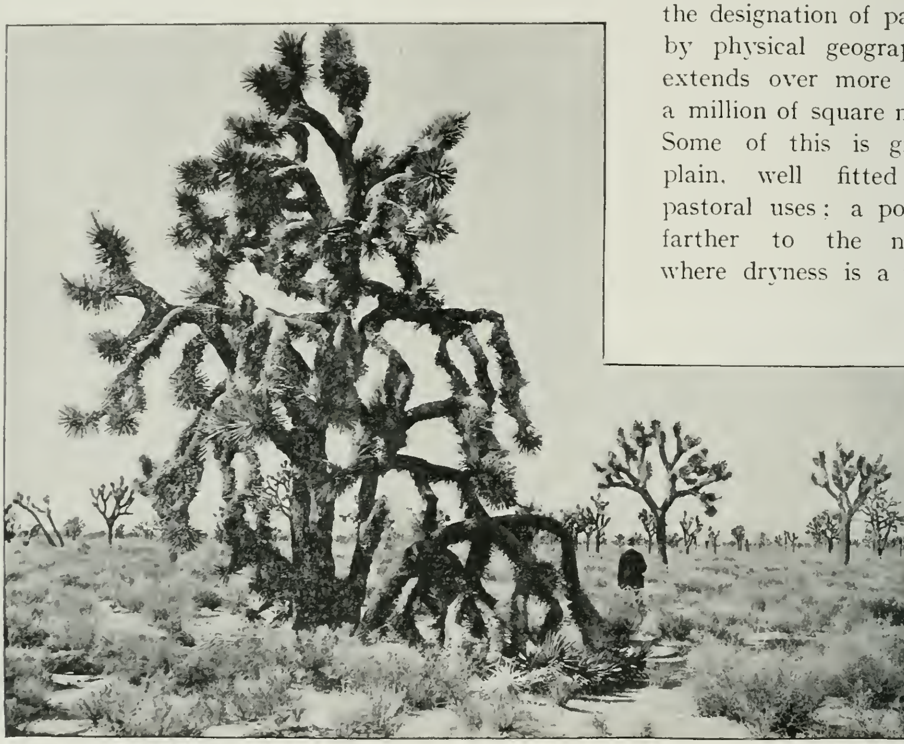


Photo — The Detroit Photographic Co.

FIG. 5.—CACTI AT HOME, IN HESPERIA, CALIFORNIA.

These curious plants have been blessed by nature with very thick and tough skins: consequently they flourish amidst arid surroundings in which few other plants can exist. Cacti are, in fact, characteristic members of the flora of hot and dry sub-tropical regions.

Before proceeding to a discussion of the causes of the peculiar condition of the surface indicated by the term steppe and the other nearly equivalent words,

it may be noticed that it seems necessary that the two features of comparative flatness of surface and absence of trees should be present at the same time, in order to give rise to so marked a type of landscape as to call for a special name. There are large treeless areas on the slopes of mountains, although the occurrence is not a common one ; but there is no special term by which such areas may be designated, and it is evident that they could not be included under any of the terms which have been mentioned. It must also be admitted that level tracts of country are much more likely to be barren of arboreal vegetation than are mountain slopes or regions with broken surface.

Before going any further, however, it will be well to notice in general what physical causes influence the character and development of vegetation. And it requires but a limited amount of observation before it will be clearly perceived that variations of temperature and in the quantity of moisture in the atmosphere have the most powerful influence on the flora of any region. In the case of temperature we see this almost equally well illustrated, whether we journey toward the Polar regions or ascend the sides of lofty mountains, the decrease of temperature manifesting itself in either case in a most marked degree by corresponding changes in the vegetation. As we pass northward the forest trees typical of warm climates are no longer present. Those characteristic of colder regions make their appearance ; these become more sparsely distributed and dwarfed in size, and finally disappear altogether. Some grasses and flowering plants maintain their hold up to still higher and colder latitudes. Finally, all these go, and only the lichens remain, of which no land, however far north it may lie, has ever been found entirely destitute. A similar experience awaits us as we ascend the slopes of high mountains. Trees finally disappear ; grasses and flowering plants higher up do the same, and the lichens maintain their hold to the last, and often until the line of eternal snow is reached. That these effects are mainly due to changes of temperature seems certain, since there is abundant evidence that differences in the distribution of moisture are not here to be considered as the principal agent.

That the presence or absence of moisture has a great influence in determining the character of vegetation cannot be denied ; and that the distribution of forests over the earth's surface is largely connected with the amount of rain-fall in different regions is beyond a doubt. An inspection of a rain-chart of the earth, and a comparison of the position of the rainless and drier areas with that of the belts or tracts destitute of trees, will be sufficient to show at once that, in a general way, regions where the rainfall is deficient are those where trees are least developed : and also that a vigorous growth of grasses may be found where the precipitation is quite moderate in amount.

That the desert regions of the world are the rainless ones cannot for a moment be doubted. Absolute deserts, however (if by the term "desert" is meant a region entirely destitute of vegetation), are not by any means of frequent occurrence ; and when such tracts do occur they rarely extend over large areas. The amount of desert on the earth is exceedingly small when compared with that of the region to which the name "steppe" may properly be applied. Moving sands form the surface least favourable to vegetation, for even a rock surface entirely destitute of soil may be more or less encrusted with lichens. Hence the fact that a considerable portion of the Sahara (*see* Coloured Plate and Fig. 1) is underlain with a sandstone which easily disintegrates on

weathering, giving rise to great masses of pure sand, is regarded as one of the reasons for the utter barrenness of such large areas in Northern Africa.

Since moisture is essential to the vigorous growth of trees, so that very dry regions are, as a general rule, not covered with forests, it will not be difficult to understand why treeless areas are usually found in the interior of continental masses, as is so well illustrated by the position of the plains of North America and that of the pampas and llanos of the southern division of the New World. The edges of the continents are the regions where the larger portion of the rainfall on the land takes place. To this rule there are but few exceptions; the most striking one is the existence of a rainless belt along a considerable part of the west coast of South America, a condition of things depending on the position of the chain of the Andes in that region with reference to the trade-winds.

But it is now necessary to proceed one step farther, and show how it is that level areas are so apt to be treeless, and thus to account for the co-existence, in so many cases, of flatness of surface and absence of arboreal vegetation.

To explain this, it will be necessary to allude to another feature of the North American landscape not yet mentioned, about which much has been written, and but little correctly stated. Writers thus far have, almost without exception, confounded the prairies with the plains in discussing the physical geography of that continent. In point of fact, however, there is a very great difference between the two. The word *prairie* was originally introduced and used in describing the geography of the valley of the Mississippi by French travellers and missionaries. Hennepin, writing about 1680, describes the prairies of Illinois, and defines them with care and accuracy. The word itself, as used in France, is almost exactly the equivalent of the English "meadow," meaning a level area covered with grass.

From a photo by the Paris Society for Evangelical Missions.

FIG. 6.—SALT PANS IN THE KALAHARI DESERT, SOUTH AFRICA.

The Kalahari Desert is an elevated basin from 3,000 to 4,000 feet high, with a length of about 600 miles and a greatest breadth of 350 miles. It extends northward from the Orange River to 21° South Latitude. Thorny scrub is the principal vegetation, and in parts there is plenty of game.

FIG. 7.—THE BOUNDLESS KAROO, SOUTH AFRICA.

Photo: J. E. Middlebrook, Durban.

It is a term now current in the United States only as applied to the treeless tracts in the immediate vicinity of the Mississippi River, and lying chiefly within the boundaries of the states of Wisconsin, Illinois, Iowa, Missouri, and Arkansas. The prairies in these states are areas covered with a vigorous growth of various grasses, interspersed with numerous flowering plants, but destitute of trees. All through the prairie regions, however, there are tracts covered with a dense growth of "timber." This seems, at first sight, to be quite arbitrarily arranged with reference to the treeless areas. Sometimes the trees occupy large tracts on the higher portions of the country; at other times—and, indeed, much more generally—they line the sides of the "bluffs," which extend along the river courses, although not in close proximity to them. These bluffs are the steeper transitional areas between the nearly level or gently undulating uplands, which form the larger part of the surface of the country all through the prairie regions, and the "river bottoms," or quite flat land bordering the streams. Although the relative position of the tracts occupied by timber and grass may seem quite arbitrary, such is not by any means the case. The reason of this distribution becomes evident enough when one examines with care the character of the soil of the region. The trees are invariably found to be growing on the gravelly or coarser varieties of soil, while that which underlies the prairies themselves is exceedingly fine—so much so, indeed, that it polishes the implements which are used in its cultivation, instead of scratching them. This extremely fine soil—which is, beyond a doubt, unfavourable to the growth of trees—is in places the result of the filling up of old lake-basins with fine sediment, but, in the true prairie region, more often the residuum left after the dissolving away of the soft, easily decomposed rocks which underlie the whole region in nearly horizontal beds. This residuum, which is almost impalpably fine, seems to have been swept into the basin in which the rocks were being deposited by marine currents coming from a great distance, and therefore bringing only the most finely comminuted material.

FIG. 8.—THE NINETY-MILE DESERT, AUSTRALIA.

On some lines of railroad running west from Chicago, on which cuts of a few feet in depth are quite frequent, so that the character of the soil can be easily recognised, and especially within the first few years after the building of the roads, the varying character of the vegetation, as one passed from timbered to grass-covered areas, could easily be recognised, in almost every instance, as being accompanied by a corresponding change in the texture of the soil. In a great majority of cases one might tell by simply feeling the soil, with the eyes shut, whether the surface was occupied by forest or by prairie.

The meteorological records which have been kept for a considerable term of years at numerous stations in the prairie region, chiefly under the direction of the Smithsonian Institution, authorise the assertion, with no possibility of any contradiction based on facts, that the prairies are not dependent for their existence on the absence of sufficient rainfall. On the contrary, the precipitation over some of the very best developed prairie areas is large—much larger, in fact, than it is over the principal portion of the forest-covered region of the Eastern States.

The theory advocated of late by some physical geographers, and especially by Peschel, for the absence of trees over extensive regions of the earth, is to the effect that it is not the want of a sufficient quantity of rain, taking the average for the whole year, but its unequal distribution at different seasons. In this way the attempt has been made to account for the existence of the North American prairies. The most careful examination of the rainfall statistics proves, however, that in the region in question there is no such irregularity of precipitation as this theory demands. The distribution through the year of the rainfall in the prairie states is in no respect different from what it is along the Atlantic border, where forests are of general occurrence. Besides, it is a fatal objection to this theory, that there are regions most densely covered with forests, where the rainfall is as irregular as possible, whether considered from the point of view of the annual average, or of the distribution by seasons. Thus, in California, along the western slope of the Sierra Nevada, forests exist which can hardly be surpassed anywhere in the world in density and absolute size of the individual trees, and yet there the precipitation is almost entirely limited to two or three months of the year, hardly a drop of rain ever falling during the period from May to November.

It is a fact, therefore, that the character of the soil has a powerful influence on the growth and character of the vegetation. Wherever, for any reason, the soil is of especially fine texture, there grasses will flourish in preference to forests, provided the rainfall be not entirely insufficient. Hence we see at once why plains are more likely than mountain slopes to be treeless. It is toward the plains that the finer materials, abraded by erosion and denuding agencies from the higher regions, are being constantly carried, as they have been in former geological ages.

Photo: The Paris Society for Evangelical Missions.

FIG. 9.—A TREK ACROSS THE KALAHARI DESERT.

THE RULER OF THE SOLAR SYSTEM.

THE sun, the mightiest and most massive body which we can see as a globe (though not the mightiest in existence), lies at a mean distance from our earth of about $92\frac{8}{9}$ millions of miles. His greatest distance (about July 3rd) is approximately $94\frac{1}{2}$ millions, his least (about January 2nd), roughly $91\frac{1}{3}$ millions of miles. It may serve to give some idea of the vastness of the sun's distance (though we cannot in reality conceive such a distance, no matter how it may be presented), to mention that an express train travelling sixty miles an hour would require more than 176 years to reach us from the sun. The sound of explosions upon the sun, if it could come to us across space, travelling at the same rate as sound in air, would reach us in something like fourteen years. Light, although it travels at the rate of some 186,000 miles per second, takes 8 min. 18 sec. to reach us from the sun.

It is very easy to find out what the diameter of the sun is when his distance is known. It will be found that any round ball must be set at a distance equal to about $107\frac{1}{2}$, or, more exactly, $107\frac{5}{12}$, times its own diameter to hide the sun exactly when he is at his mean distance (about April 2nd and October 4th). Hence we learn that the sun's distance exceeds his diameter $107\frac{5}{12}$ times. His diameter is therefore approximately 866,400 miles, or exceeds the earth's nearly $109\frac{1}{2}$ times. It follows that the surface of the sun exceeds the earth's about 11,970 times, while in volume the sun exceeds the earth about 1,310,000 times. Of these three relations, *diameter*, *surface*, and *volume*, the second—surface—is altogether the most important, since it is from the surface of the sun that we receive the supplies of light and heat which make the sun the light, as he is the life, of the solar system. Fig. 1 shows the relative dimensions of the sun and of the earth.

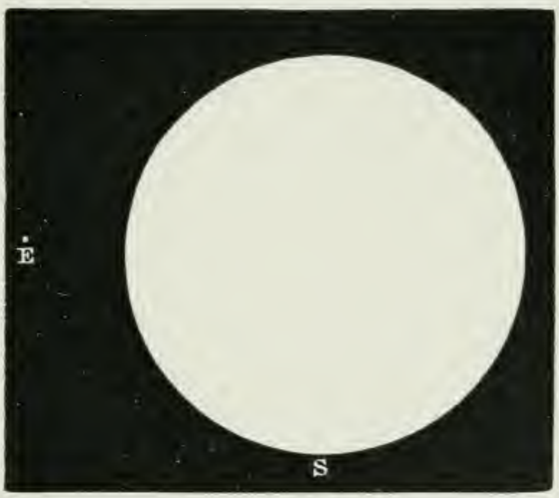


FIG. 1.—SHOWING THE RELATIVE DIMENSIONS OF THE SUN (S) AND OF THE EARTH (E).

But we have to consider next a relation far more important—that quality of the sun by virtue of which he is enabled to bear sway over the solar system—his *mass*.

The various methods by which the distance of the sun has been determined have been referred to in the chapters upon the minor planets and the planet Venus. But the determination of the sun's mass may properly be considered here.

Newton proved the earth's gravity to

be the force which controls the moon in her orbit, by showing that the force which draws bodies earthwards requires only to be reduced in a degree corresponding to the moon's distance, to become exactly equal to the deflective force earthwards which the moon constantly experiences as she travels round our earth. Now, we know what is the deflective force sunwards which the earth experiences as she journeys round the sun. We know also her distance from the sun, and the length of the time (one year) in which her circuit is completed. When we calculate from these data* how great the force is which is constantly deflecting the earth sunwards, we find that the pull of the sun at the earth's distance is less than the pull of the earth on bodies at her surface (or 3,959 miles from her centre), in about the proportion of 1 to 1,659. But since the sun's distance exceeds 3,959 miles about 23,470 times, or is reduced (as compared with the earth's on bodies at her surface) 23,470 times 23,470 times, it follows that at equal distances the sun's pull exceeds the earth's as 23,470 times 23,470 exceeds 1,659, or roughly 332,000 times. But we know that the force of gravity depends directly on the quantity of matter. Wherefore, we learn that the sun's mass exceeds the earth's 332,000 times. This proportion is not so great as that (1,310,000 to 1) in which his volume exceeds the earth's. It follows that his mean density is less than the earth's in the same degree that 332,000 is less than 1,310,000, or roughly his *mean* density is about a fourth of the earth's. *The actual density of his internal regions* may be far greater. According to the best estimates yet obtained, our earth's mean density is about 5·53 times that of water. It follows that the sun's mean density exceeds that of water as 7 exceeds 5, approximately.

To afford an idea of the tremendous power residing in the sun's mass in virtue of its gravitating energy, let it be noticed that if our earth, without being larger than it now is, contained as much matter as the sun, every object on its surface would be drawn downwards with a force exceeding 332,000 times that with which it is actually drawn. Thus, a mass which now weighs one ounce would weigh 332,000 ounces, or about 9 tons. A man of average size would be crushed to the earth under a weight of about 25,000 tons.

Such is the energy residing in the sun's mass. If we could imagine it all gathered into a point-like globe, this globe would exert the attraction just described on bodies at a distance of 3,959 miles. But as the sun's globe is very large, no mass is actually exposed to this tremendous attraction; for any mass outside of him lies more than 433,000 miles from his centre. But even at his own surface, or what seems to us his surface, his attraction is tremendous, exceeding terrestrial gravity $27\frac{2}{3}$ times. At the distances of even the nearest members of his family the sun's attraction is, of course, far less than terrestrial gravity. The motions of all the planets are such—the nearer travelling the more swiftly—that the sun's force suffices to keep most of those orbs travelling in paths of small eccentricity around him. Thus, their distances from him do not greatly change as they complete their circuits, and they receive from him a nearly uniform supply of light and heat. In the case of Mercury, however, and in less degree in that of Mars, the change of distance is large enough to make the

* The calculation may be left as an exercise for the student; but the following hints may help him:—Let him first find how far the earth travels in a second—he will find the distance to be about $18\frac{1}{2}$ miles. Add the square of $18\frac{1}{2}$ to the square of 92,800,000; the square root of the sum will be the earth's distance from the sun at the end of the second, if the sun's gravity had not acted; and taking 92,800,000 miles from this, we get the amount by which, under the action of gravity, the earth has been deflected towards the sun. It will be a very small decimal of a mile, and must be reduced to the decimal of a foot, for comparison with gravity at the earth's surface.

supply of light and heat vary considerably in the course of the planet's circuit round the sun.

Now let us consider what the telescope tells us about this wonderful globe—the ruler of the solar system.

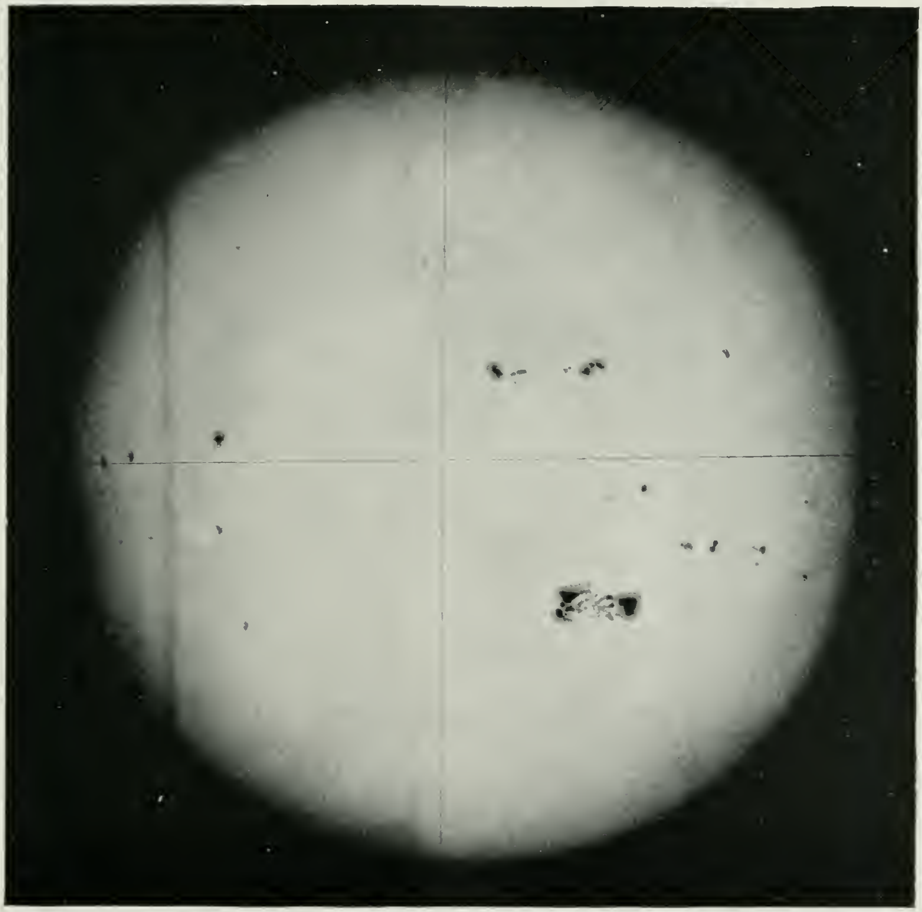


FIG. 2.—PHOTOGRAPH OF THE SUN'S DISC TAKEN AUGUST 8TH, 1893, AT THE ROYAL OBSERVATORY, GREENWICH.

(By permission of the Astronomer Royal.

It was in the year 1611 that Fabricius, Galileo, and Scheiner first studied the sun with the telescope. They discovered that there are spots on the sun's surface. They saw the spots move across the sun's face from east to west, and at first they supposed these spots to be bodies travelling round the sun. But after a time they recognised the fact that the spots are, as it were, surface-markings, carried round with the sun as it rotates on its axis. They also found that the spots are not permanent features, but last only for a few weeks or days, as the case may be. It would be interesting to follow the actual progress of their observations and subsequent telescopic study of the sun; but the requirements of space render it more convenient here to proceed at once to consider the results to which such researches have led.

Fig. 2, which is reproduced from an actual photograph, represents the general aspect of the sun at a time when there

was a large number of spots upon its surface. It will be seen that the spots are not uniformly dark, but show certain dark, almost black, portions, round which lies a region of dusky tint. The dark part is called the *umbra;* the border region is called the *penumbra.* When a telescope of considerable power is used, and the field of view is so reduced that only the umbra of a spot can be seen, it is found that the umbra is not black, and often there can be seen in the middle of the umbra a darker spot, which has been called the *nucleus* (Fig. 3).

FIG. 3.—GROUP OF SUN-SPOTS SHOWING THE "NUCLEUS."
From a photograph taken at the Royal Observatory, Greenwich, September 9th, 1898.
(By permission of the Astronomer Royal.)

These spots are often of immense size. Thus, on February 13th, 1892, a great spot was seen, of which the extreme length was 92,000 English miles and its breadth 62,000. The entire group of which it formed the principal part was 162,000 miles in length and 75,000 in greatest breadth. Then, again, in September, 1896, a single group was seen extending very nearly continuously for more than 180,000 miles. The breadth of this group, however, did not exceed 35,000 miles at its broadest part. The area of the great spot of February, 1892, reached the astonishing amount of 2,940,000,000 square miles. Sixty globes, therefore, as large as our earth could have lain side by side in that vast area; or, if the entire group be taken of which this great spot was the principal member, more than seventy could have been included. On the other hand, the smallest spots are just on the limit of visibility in the telescope, and have diameters of 200 miles and under.

The first fact learnt from the observation of sun-spots was that the sun rotated upon its axis. Not a few spots last for two or three months, or even longer, and sometimes show but little change in form or size during the greater portion of their life history. Many of them first form on the visible hemisphere of the sun, but more take their rise in the unseen hemisphere, and first come within the range of our scrutiny at the eastern limb of the sun as it rotates. A spot so seen will on the first day appear either as a very shallow notch in the sun's limb or as a narrow line just within it and parallel to it. On the second day it will have advanced but little from the limb, but be distinctly broader than when first seen. By the third day it will have advanced sufficiently far on the disc for its principal details to be perceived, though it will still be considerably foreshortened. Its apparent motion will seem to increase by the fourth day, when it will be pretty fully presented. It will pass the centre of the disc about the seventh day of observation, and will reach the west limb about the thirteenth day. It will then be lost to view for about fifteen days, appearing on the twenty-eighth or twenty-ninth day a second time at the east limb. The average period taken by a spot to travel from the central meridian of the sun round to that meridian again is 27¼ days. This is not, however, the actual time of the sun's rotation, for it must be

remembered that the earth is travelling round the sun in her orbit the whole time. In 27 days the earth has travelled very nearly one-thirteenth of her course round the sun. In order, therefore, for a particular point on the sun's surface to come a second time to the centre of his disc, as seen from the earth, the sun must perform not merely one complete rotation, but a thirteenth more. The actual rotation period of the sun, therefore, is approximately $25\frac{1}{3}$ days.

The accompanying diagram (Fig.4), showing the apparent position upon the disc of two spots day after day during one complete apparition, shows that the apparent path of each spot—or, in other words, a circle of solar latitude—was at the time of observation inclined at a very considerable angle to the N. and S. line. The sun's axis is not perpendicular to the ecliptic, but inclined at a considerable angle to it—about 82° 45′. The longitude of the ascending node is about $74\frac{1}{2}$°. Owing to the inclination of the ecliptic to the terrestrial equator, the sun's axis may be inclined as much as $26\frac{1}{2}$° to the N. and S. line, the great circle drawn from the pole of the heavens and passing through the centre of the sun's disc. This maximum inclination takes place about April 6th, when the northern end of the sun's axis lies to the west of the N. and S. line, and again about October 10th, when it lies to the east. The sun's axis coincides with the N. and S. line about January 5th and July 7th.

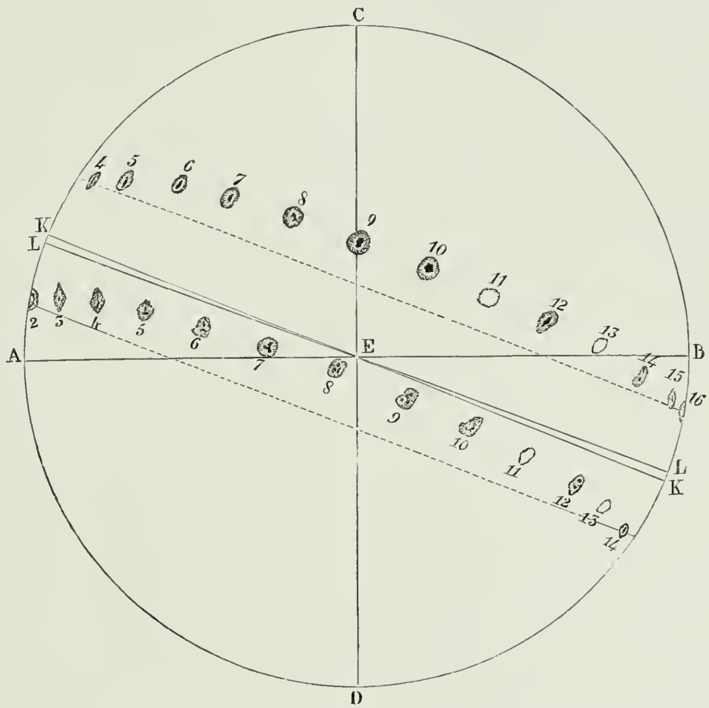


FIG. 4.—THE SUCCESSIVE POSITIONS OF TWO SUN-SPOTS UPON THE SUN'S DISC, AS OBSERVED BY FATHER SCHEINER IN MARCH, 1867.

The numbers attached to the spots indicate the days of the month when they were seen in the position shown.

(From Scheiner's "Rosa Ursina.")

Directly the position of the sun's equator was determined, it became evident that the spots did not appear indifferently all over the solar surface, but were strictly confined to certain zones. The great majority of the spots are found in the region lying between latitude 5° and

latitude 25° on each side of the equator, and they are most numerous towards the middle of this zone. It is very seldom indeed that any spots, except exceedingly small and short-lived ones, are found in a higher latitude than 35°, though there are a few instances on record in which some small and transient markings have been seen as high as latitude 50°.

It was stated just above that the mean time of the sun's rotation on its axis was $25\frac{1}{3}$ days. This is the average time deduced from observation of a great number of spots in all latitudes. It was, however, very early noticed that different spots appeared to move with different rapidities, and in 1860 Carrington, one of the most careful and systematic of observers of the sun, showed that, on the whole, spots nearer the equator moved faster than those at a greater distance from it. The rotation period for the equator is about 25 days; for latitude 30°, $26\frac{1}{2}$ days; for latitude 40°, 27 days; for higher latitudes than 40° no really trustworthy rotation period can be deduced from observations of spots.

The variation of the spots in number at different times is one of the most remarkable of all the facts known respecting them. The discovery was made by the late Herr Schwabe, of Dessau. From a series of observations commenced in the year 1826, and carried on for nearly half a century, he found that the spots increase and diminish in number in an almost regular manner. From the time when they are most numerous they gradually diminish in number, until at length none are seen; then after a year or two, during which scarcely any spots are seen, they increase in number until they again attain their maximum frequency. The entire interval between two successive epochs of greatest frequency is about 11 years $1\frac{1}{2}$ months. But although in any very long period this interval is recognised as the average, the actual interval between two successive epochs of greatest spot-frequency often exceeds or falls short of 11 years $1\frac{1}{2}$ months by one or two years.

Since Schwabe's discovery Wolf of Zurich and Spoerer of Potsdam have collected together sun-spot observations reaching back to the year 1611, when they were first seen in the telescope, and have shown that the ebb and flow of solar activity has gone on fairly regularly during the whole of that time. Professor Newcomb, discussing the entire series of observations, finds that though occasionally a cycle will be completed in less than 10 years, or be prolonged to more than 12, yet that underlying all the periodic variations of sun-spot activity is a uniform cycle of 11·13 years in length, of which period 4·62 years are occupied in the rise from minimum to maximum and 6·51 in the decline from maximum to minimum. It should be noted, however, that during the latter half of the seventeenth century sun-spots appear to have been very infrequent. The 11-year cycle can, indeed, be traced during that time, but the maxima were often not more prolific than some minima have been.

The change in the size and numbers of sun-spots is associated with a curious change in position. When the sun-spot minimum has just been passed and spots are beginning to multiply, they are usually found at a considerable distance from the equator. During the further progress of the cycle, as the spots attain their maximum development and then decline, the region most affected by them slowly approaches the equator, until just before the next minimum the spots are practically confined to the region within 10° on each side of the equator. At this juncture a few small spots begin to appear in high latitudes, the forerunners of those of the next cycle. Thus at minimum it is not unusual to find three well-marked zones; two zones, the one north and the other south of the equator, in

latitudes 25° or 30°, consisting of spots belonging to the new cycle; and the third zone, close to the equator, of spots belonging to the cycle that has nearly passed.

The minuter changes in the numbers of sun-spots are of considerable interest. The progress of any particular cycle is by no means smooth and regular, but short periods of greater disturbance alternate with intervals of comparative quiet. But, as a general rule, whenever there is a temporary increase of the numbers or areas of the spots, there is also a tendency for them to appear in somewhat higher latitudes.

These dark spots are not the only markings on the solar surface; indeed, the better it is seen, and the greater the magnifying power applied to it, the more diversified it appears to be. Every part of it is covered with multitudes of small, bright dots with darker intervals separating them, producing on the whole a mottled appearance. Several different names have been applied to the minute bright points making up this structure: they have been called "granules" and "rice grains" or "willow leaves." If a photograph be taken of the sun on a large scale, and with very short exposure, this mottling becomes quite obvious, and the general surface of the sun, instead of being one sheet of uniform brightness, resembles rather a photograph of a piece of coarse cloth. Janssen, at the Meudon Observatory, making a special effort to emphasise this mottling, discovered that the mottling itself changed its character with the progress of the solar cycle, and at the time of maximum activity the granules composing it were distributed in a peculiar and strongly marked network, to which he gave the name of *réseau photosphérique* (Fig. 5).

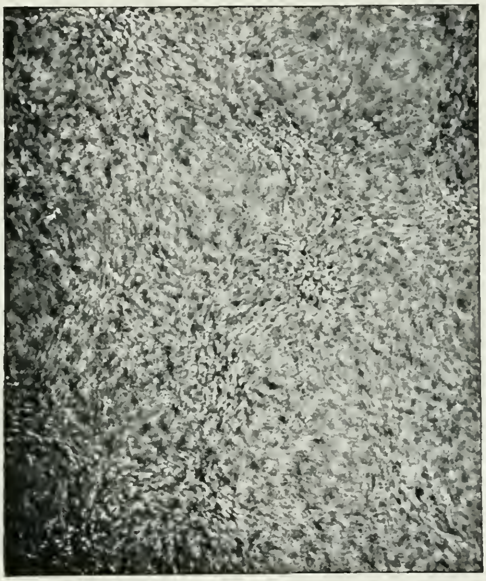


FIG. 5.—A PORTION OF THE SOLAR SURFACE, SHOWING MOTTLING.
(From the "Annals" of the Meudon Observatory.)

Here and there on the sun the bright granules are clustered together in long, branching ridges, shaped like pieces of coral, and much brighter even than the general surface of the sun. These bright streaks were recognised by the first observers of the sun's spots, and received from Hevelius the name of *faculæ*, from the Latin word *facula*, "a torch." They are not restricted to the spot zones, but appear in all latitudes. They vary in number, area, and brightness with the progress of the solar cycle, being, on the average, most conspicuous where there are most spots, and *vice versâ* (Fig. 6).

A careful examination of the sun, or of a good photograph of it, will show at once that its centre is considerably brighter than its circumference. This has been supposed to be due to the presence of a "dust veil," a shell of finely divided dark matter completely surrounding it. As we necessarily see the limb of the sun—that is to say, the part near the circumference—through a much greater depth of this dust veil than the parts near the centre,

the former suffers a greater loss of light. On this account the *faculæ* are more conspicuous near the limb than near the centre; for, being elevations above the general surface, they rise above the greater part of the dust veil, and hence their brightness is but little dimmed by it. They show up, therefore, much more conspicuously against the comparatively sombre regions near the limb than when seen nearer the centre of the disc.

In the case of the formation of a group of spots, the order of events is usually as follows. The region in which the group

FIG. 6.—GROUPS OF *FACULÆ* OR BRIGHT STREAKS MAY BE FREQUENTLY OBSERVED ON THE SURFACE OF THE ORB OF DAY.
From a photograph taken at the Royal Observatory, Greenwich, September, 21st, 1896.
(By permission of the Astronomer Royal.)

is about to appear will, if favourably situated for observation, first begin to show a few bright, faculous ridges. Then one or two small, faint spots appear. As the disturbance grows, it tends to develop along a parallel of latitude, and forms what has been termed a "train" or "stream" of spots (Figs. 7, 8, 9, and 10). Soon this train shows three well-marked regions. First of all is a spot of well-marked outline and nearly circular in shape; then come a great number of small, ill-defined, and irregular spots; and last of all is a large spot, frequently the largest of the group, of more or less irregular outline. During the next stage the leader increases in size, and moves forward on the solar surface, with a speed of 300 to 400 miles an hour, away from the other members of the train. The small spots in the centre of the group then die out, and the leader and rear spot remain as a pair. Usually the rear spot breaks up and disappears, leaving the leader alone. The leader survives as a well-marked circular spot, often for a couple of complete rotations of the sun, and gradually dwindles down till it disappears, or perhaps separates into a number of small spots and disappears more quickly. The last stage of the group, therefore, greatly resembles in appearance its first commencement.

The movements to and fro upon the solar surface of a spot group during its development and decay are often most irregular, but the movements in longitude are always greater than those in latitude, and if, as not infrequently happens, the axis of the spot group at formation is inclined to the equator, there is a well-marked tendency to come quickly into parallelism with it.

The foregoing peculiarities, and several others which might be named—as, for example, the way in which one single region of the sun's surface will be the seat of a long succession of disturbances—all point to the origin of these manifestations as lying deep down within the body of the sun itself. The period of the solar cycle (11·13 years), is so nearly that of a revolution of Jupiter (11·86 years), that at one time it was thought that that giant planet might be the true cause of these disturbances. Now that the length of the cycle has been precisely fixed, and we are better acquainted with the nature of sun-spot changes, that theory has been definitely abandoned.

But the question has been raised

whether, if the planets do not give rise to the sun-spots, the sun-spots might not influence the planets, and our own world

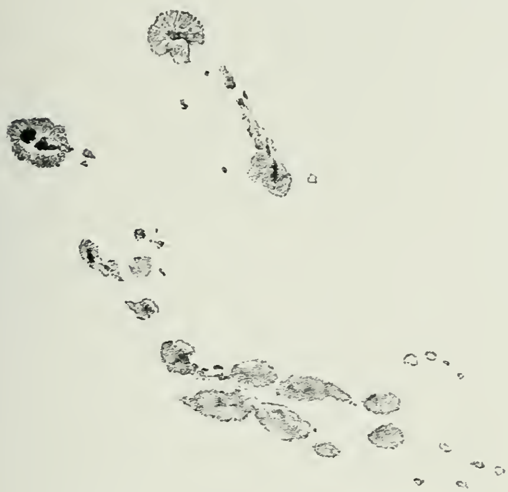


FIG. 7.—TWO TRAINS OR STREAMS OF SPOTS SEEN OCTOBER 29TH, 1892.

These spots, as well as those shown in Figs. 8, 9, and 10, are from drawings by the late Miss E. Brown.

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in particular. At first sight, it seems exceedingly plausible to suppose that a spot-group like that of February, 1892, so large as not only to be visible to the naked eye, but to be very conspicuous, with a total area of some 3,500 million square miles, must make some appreciable difference to us, and must very notably affect our weather. Several astronomers believe

A *B*

FIG. 8.—TYPES OF SUN-SPOTS.

A. Pair of spots seen November 8th, 1892.
B. Normal spot, August 8th, 1892.

that they have shown a connection between terrestrial weather changes and the progress of the sun-spot cycle, but the evidence in favour of such a connection is far from strong, and the best authorities generally agree that no such connection has been at all clearly established.

But in one respect there is an undoubted answer on the earth to the changes of the sun-spot cycle. If a magnetic needle be freely suspended, it will take up a certain position, which in this country is not parallel to the meridian, but inclined to it at an angle of about 16°. The needle will not, however, remain perfectly stationary, but in the course of each twenty-four hours will move slightly towards the west from about eight o'clock in the morning to about two o'clock in the afternoon, and then back again towards the east during the night, a movement evidently due to the influence of the sun (Fig. 14). The amount of this movement varies in the course of the year, the mean daily range of move-

FIG. 9.—COMPOUND SPOT OF JUNE 30TH, 1883.

ment of the magnetic needle being twice as great for the four summer months, May to August, as for the four winter months, November to February. The solar influence is thus evident in a second relation (Fig. 12). But beside these daily and annual periods, a third is very distinctly marked which coincides with that of the sun-spot cycle. The average "diurnal range of magnetic declination," as this daily oscillation of the magnet is termed, is greatest when there are most spots on the sun and smallest when there are least (Fig. 14). More than this, from time to time the needle undergoes short paroxysms of movement—magnetic

storms, as they are called — and the very greatest of these have taken place when some abnormally large sun-spot has been near the centre of the solar disc.

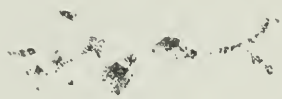


FIG. 10.—ZIGZAG OR IRREGULAR STREAM OF SMALL SPOTS (APRIL 5TH, 1886).

In close agreement with these magnetic storms has been the occurrence of great displays of auroræ. Whether these magnetic storms and auroral displays are directly caused by the sun-spots, or whether the connection between them is of a secondary character, is not yet known. That the connection, whether direct or indirect, is real and effective is obvious.

But what are the spots? The impression produced by a well-defined spot when seen near the centre of the disc is certainly that of a rent—a cavity—in the solar surface. The spot is surrounded by a bright and therefore apparently raised region, and the half-light of the penumbra and the darkness of the umbra seem to belong to successive lower layers. Further, the bright matter from the neighbourhood of the spot is often projected across it or flows down into it, in either case increasing the impression that the spot is a hollow.

It sometimes happens that the appearance presented by a spot when near the limb, and seen much foreshortened, gives rise to just the same impression. Thus Dr. Wilson, of Glasgow, observing a very large roundish spot, which was visible on the sun in 1777, found that the dark part of that spot, at any rate (whatever might be the case with others), lay below the penumbra. As noted above, the spots move across the sun's disc from east to west (Fig. 4). Now it is obvious that such a spot as the largest shown in Fig. 3, if it were really a surface-marking, would be foreshortened in the same way, whether on the eastern or on the western side of the sun. The spot would be narrowed, and the penumbra on either side of the umbra would be narrowed in the same degree. But if a spot is either an elevation or a depression, this will not happen. Suppose a spot is a saucer-shaped depression, for instance, the dark umbra corresponding to the bottom of the saucer. Let A (Fig. 13) represent the *interior* of a saucer, the shaded part being the bottom. Then such a saucer, placed in the position of the spots numbered 3 and 4 in Fig. 4 (p. 253), would appear as shown at C; and

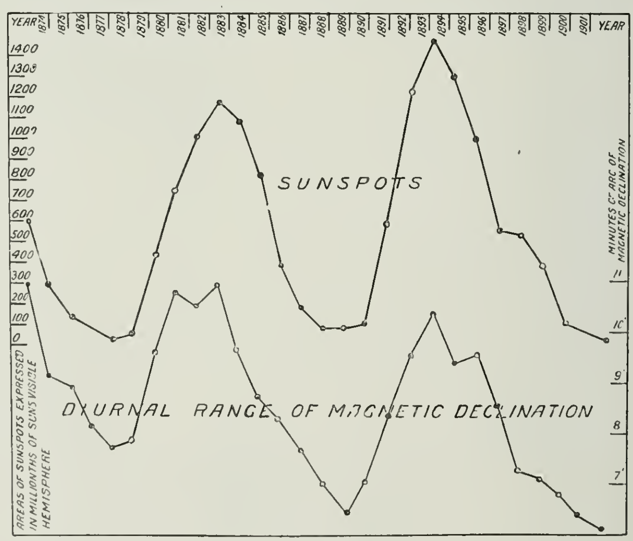


FIG. 11.—AREAS OF SUN-SPOTS COMPARED WITH THE DIURNAL RANGE OF MAGNETIC DECLINATION.

if placed in the position of those numbered 14 and 15, would appear as shown at B. Whereas, if A represents the *exterior* of a saucer, the aspect B would be presented by the saucer in the position of spots 3 and 4, and the aspect C by the saucer placed like spots 14 and 15. Now, Wilson

noticed that the great spot of the year 1777 changed in aspect in the former way, not in the latter—that is, behaved in such a way as to show that the umbra lay

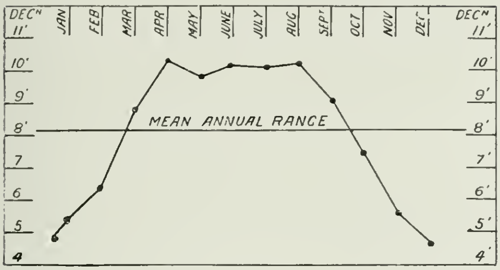


FIG. 12.—MONTHLY MEAN DIURNAL RANGE OF MAGNETIC DECLINATION.

below the general level of the sun's surface, the penumbra forming the slant sides of a saucer-shaped depression. He found that, as the spot passed over from the middle of the sun towards the west, the penumbra, which had been equally wide all round, no longer remained so. On the eastern side the penumbra rapidly narrowed, while on the western side it remained unchanged in breadth, or nearly so. At length, when the spot had drawn very near the western edge of the sun, the eastern side of the penumbra disappeared altogether, while the western still retained considerable breadth. But when, after being out of view for half a rotation, the spot reappeared on the eastern side of the sun, its aspect was entirely changed. No penumbra was visible on the western side, while the eastern penumbra was broad and well defined. As the spot approached the middle of the sun's face the penumbra recovered its original equality of breadth. As the spot passed over to the western edge, the appearances before recognised in that neighbourhood were repeated.

Mr. Howlett and several of the best modern observers have found, however, that the appearances described by Wilson are only occasionally presented; Mr. W. E. Wilson, of Daramona, has shown that though, when seen near the centre of the disc, a sun spot radiated less heat than the general surface, yet near the limb the difference became less, and in some cases was even reversed, suggesting that the umbra was higher than the general surface, and not below its level. Some observations recorded by Mr. Maunder tend to reconcile these different ideas by suggesting that the umbra has a dome-like contour; so that, though below the penumbra, which, again, is below the general surface, yet the centre of the umbra may often rise above the general level.

We have thus far considered the sun only as the ruler of the solar system, and as the telescope presents him to us. We have still to inquire into the sun's actual condition, to learn what he is made of, at what heat he subsists, how the supply of heat which he constantly emits is probably maintained, and to consider also the wonderful appendages which surround his globe, but are visible only when the glory of his face is concealed in total eclipse. These matters are far too interesting to be dealt with cursorily in the short remaining space here available. They will, therefore, be separately considered in another paper.

To sum up what we have learned

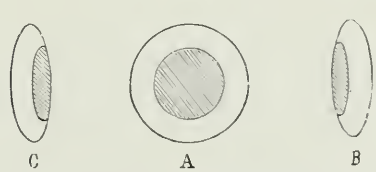


FIG. 13.—SHOWING HOW THE CHANGES SEEN IN SUN-SPOTS AS THEY CROSS THE SUN'S FACE ARE EXPLAINED.

respecting the sun as ruler of the solar system:—

The mighty orb of the sun lies at a mean distance of $92\frac{8}{9}$ millions of miles from the earth, his greatest, mean, and least distance being relatively as the

numbers 61, 60, and 59. His diameter is 866,400 miles, exceeding the earth's about 109½ times. He exceeds the earth in surface 11,970 times; in volume 1,310,000 times; in mass (and therefore in attractive energy at equal distances) 332,000 times. The telescope shows that the sun's surface is not ordinarily of uniform brightness, but is marked by spots, which vary in size, number, and duration. The largest have had a diameter of more than 100,000 miles. Some spots last only a few days; others for several months. Examined with high telescopic power, the sun's surface is found to be covered with multitudes of small, bright dots, which by their irregular aggregation produce the appearance called mottling; while the crowding together of the grains into long streaks forms the faculæ. Spots are only seen in comparatively low latitudes, seldom being seen further from the equator than 35°. But faculæ are seen all over the sun, though most frequently in the spot-zones. The solar equator-plane is inclined about 7¼° to the plane of the ecliptic. The earth crosses the extension of the sun's equator-plane on December 6th and June 5th. Spots wax and wane in number in a period averaging about 11⅛ years; less marked periods probably exist, though, as yet, they are not certainly established. The earth's magnetic condition varies with the condition of the sun, the time of greatest magnetic disturbance agreeing with the time of most spots. When the spots first begin to show after a spotless interval, they are seen in high solar latitudes; but they appear in lower and lower latitudes (on the average), the last representations of each spot period appearing quite close to the equator.

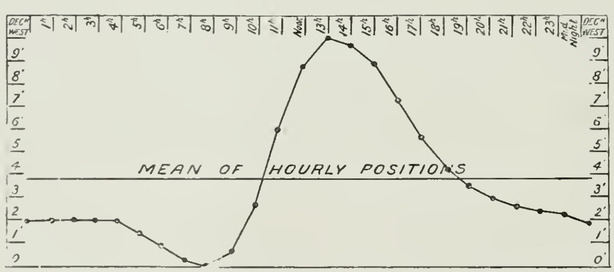


FIG 14.—SHOWING THE MEAN RELATIVE VARIATION OF THE DECLINATION MAGNET DURING 24 HOURS.

THE CONQUEST OF THE AIR.

By the Rev. J. M. BACON

If records dealing with the seemingly marvellous in times two hundred years agone can be trusted, it would appear that more than one plausible endeavour to gain dominion of the sky by simulating flight was made as early as the seventeenth century, if not, indeed, before. The mode usually adopted was apparently that of gliding through the air by mechanical means (*see* Figs. 1 and 2), an achievement which has been revived and brought to considerable perfection in recent years, and which will receive notice in due place.

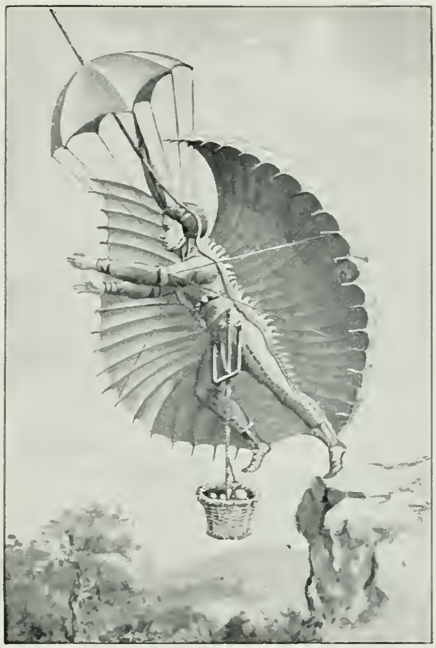


FIG. 1.—A FLYING MAN.

But probably earliest among those attempts which were made in serious earnest, and which met with any true measure of success, must be mentioned that of Besnier, of Sable, a locksmith, who constructed a simple apparatus consisting of a pair of double-bladed paddles, which he operated with his arms and legs, somewhat after the manner of a dog swimming, and thus succeeded, laboriously enough, in a species of abortive flying. But real dominion over the air was not to be won in this way, and it was not till well on in the eighteenth century that the true dawn of aëronautics, properly so called, began to manifest itself. Cavendish and Black, both our own countrymen, may be claimed as among the chief pioneers—the former, a Cambridge student and physicist, by his discovery about the year 1760 of the properties of hydrogen gas; the latter, a doctor of Edinburgh, by his suggestion that the same gas might be used to make bodies float in air. This idea was adopted by Cavallo, a philosopher of Naples, who made soap bubbles blown with the new gas sail upwards.

But it was reserved for two Frenchmen—the brothers Montgolfier, paper-makers, of Annonay—to invent the first real airship, and their brilliant discovery was as much the result of happy chance as of inventive faculty. Starting with the ingenious conception that because smoke ascended therefore light bodies might float if simply filled with smoke, they experimented in this direction with bags made of their own paper, and soon found that such bags, when inverted, would become inflated and buoyant by merely keeping a fire below the open mouth. The true principle here involved, but imperfectly understood at the time, was, of course, that the heated air within the bag became rarefied, and therefore lighter than the surrounding air.

But the great secret had now been wrested from Nature, and within six months the two young Frenchmen enjoyed the triumph of exhibiting to the world the inflation, by means of a furnace, of a paper balloon measuring 23,000 cubic feet, which presently sailed high into the sky and travelled a mile away. This experiment proved not only that the principle of the balloon, but the possibility of its employment as a means of locomotion, had been fully grasped, and its further development seemed already simply a matter of numerical calculation. Supposing the mere mechanical difficulties of due inflation with hot air could be met, then, as was at once self-evident, other things being equal, the larger the machine the greater would be its lifting power. This follows from simple geometry, since the surface of a globe increases as the square of its radius, while the cubic content increases as the cube of the radius. Thus, to come to approximate figures, the fabric of a balloon of 20 feet diameter would measure 1,257 square feet, and this when inflated would have a capacity of 4,188 cubic feet. But a balloon of twice this diameter, while having a surface of 5,028 square feet, would possess a capacity of no less than 33,510 cubic feet.

FIG. 2.—AN AËROSTATIC MACHINE.

We are thus prepared to find that the inventors quickly increased the dimensions of their aërial machine, and shortly, having completed a noble craft of 48 feet diameter and more than 70 feet high, they essayed to launch it into space with any passengers who had courage enough to hazard the first voyage into the skies. Nor was there any delay. A preliminary and perfectly satisfactory experiment with living animals being first carried out, the courageous and ever memorable feat was accomplished by two Frenchmen, M. Pilâtre de Rozier and the Marquis d'Arlandes, in the month of October, 1783, or scarcely one year from the night when the first idea of the balloon was conceived. The two intrepid voyagers above mentioned ascended from Paris, and, taking up and tending their own furnace, rose some 3,000 feet, crossed the city and river, and descended in safety in the open country beyond.

Ere this great feat had been accomplished, another and all-important triumph in aëronautics had been won. It has already been explained that the true principle involved in the inflation of the Montgolfier balloon had been somewhat misunderstood, for it was supposed that the lifting power generated was due not so much to the rarefaction of the air as to the evolution of some light gas during the combustion of the material used as fuel. This at once revived

among chemists the notion, already spoken of, that hydrogen gas, or *inflammable air*, as it was then called, might be used for balloons. And with manifest advantages, for in the first place it was the lightest of all gases, and secondly, as no furnace would be required, the great element of danger would be removed, and the accommodation for passengers could be a simple car suspended below the mouth of the balloon instead of an outside gallery remote from the stove, to which it had been necessary to resort.

M. Charles, Professor of Experimental Philosophy at Paris, with two mechanical assistants, the brothers Roberts, undertook the design and management of the new form of balloon, and one of small dimensions was constructed and successfully launched, having, however, its neck securely tied. In consequence of this oversight—or, rather, of this mistaken precaution—the balloon, on reaching a lofty altitude where the external pressure of the air became diminished, necessarily burst, by reason of the expansive force of the gas within it. An all-important lesson was thus learned; and, partly as an outcome of this mishap, M. Charles is credited with being the inventor of two fundamental essentials in balloons—a valve to allow of the discharge of gas, and a suitable varnish to prevent its undue escape through the silk.

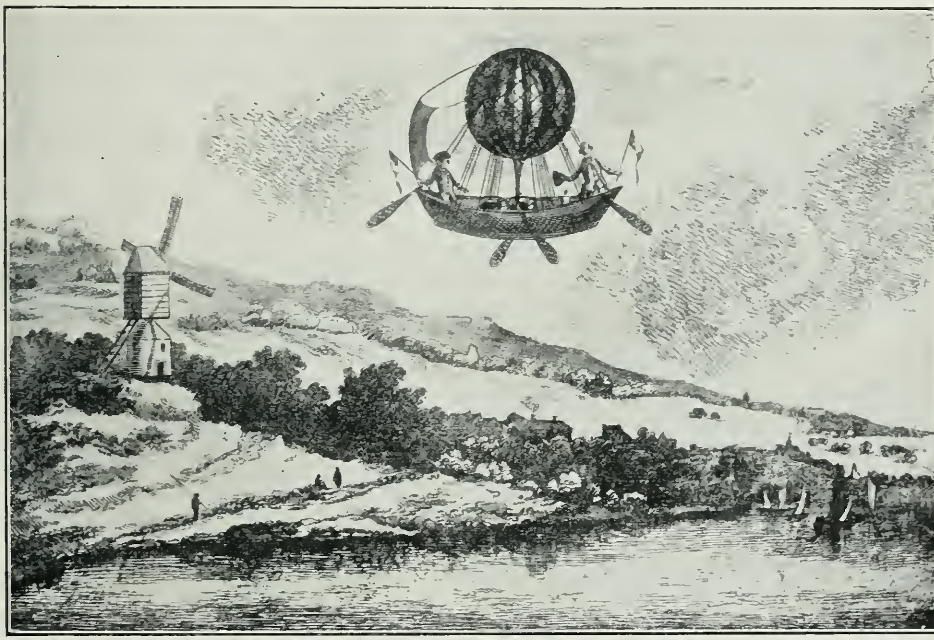


FIG. 3.—BLANCHARD AND JEFFRIES MAKING AN ASCENT.
It was these intrepid aëronauts who first essayed the passage of the Channel in a balloon, January, 1785.
(From an engraving in the British Museum.)

Ere the year 1783—the year already so famous in the annals of aërostation—had closed, M. Charles, in company with one of the brothers Roberts, made the first ascent—a long and lofty one—in a true gas balloon, which, it may be said, was in all essential particulars identical with those in use at the present day.

Ballooning enterprise now set in in earnest, and among many memorable exploits must be mentioned one of singular daring accomplished, in the beginning of the year 1785, by a French aëronaut,

M. Blanchard, accompanied by Dr. Jeffries, an American physician, using a hydrogen balloon. This was the crossing of the English Channel (Fig. 3), and the voyage, though in the end successful, proved instructive owing to a serious difficulty which should have been guarded against, and which resulted solely from the want of knowledge. The start, which was made from Dover, was delayed till a January sun was near its setting, and the chilling and shrinking of the gas that, as a natural consequence, ensued, caused an untimely descent of the balloon. Actual disaster was ultimately avoided, but not until a new and important lesson had been taught by alarming experience.

In the summer preceding the enterprise last recounted, ballooning—though chiefly of a sensational nature—had found its way to England. A Mr. Tytler, of Edinburgh, succeeded in making a modest but daring leap into space in a hot-air balloon from which the stove was previously removed, and is thus credited with having made the first ascent from British soil. This feat was quickly eclipsed by the brilliant achievements of the young Italian, Vincent Lunardi, who, being in England attached to the Neapolitan Embassy, found both leisure and funds with which to apply himself to the new-born art. This ardent adventurer, with admirable courage and perseverance, and in spite of much difficulty and opposition, succeeded in constructing his own balloon, and, with the assistance of Dr. Fordyce, inflated it in the grounds of the Hon. Artillery Company, London, whence he accomplished an aërial voyage which terminated in perfect safety near Ware. This was in September, 1784, and during several months following this brilliant amateur, with equal success and good fortune, carried out a number of bold ascents in Scotland and elsewhere.

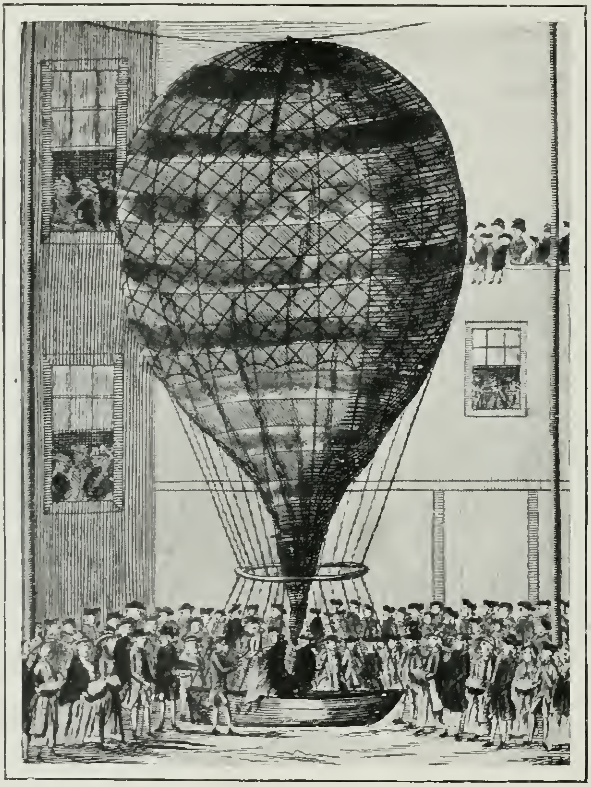


FIG. 4.—COUNT ZAMBECCARI'S BALLOON.
The balloon is one of the Montgolfier type.
(From an engraving in the British Museum.)

It should here be noticed that the process adopted for generating hydrogen gas on a scale adequate to a balloon inflation was generally that depending on the action of dilute sulphuric acid on zinc or scrap-iron. Large casks were employed for the generation of the gas, which was cooled and purified by being passed through water, and thence conducted through silk hose into the balloon.

The invention of an airship being now an accomplished fact, the next development in aëronautics was to be that of the parachute, and this now quickly followed. As early as 1785 M. Blanchard—of whom mention has already been made—succeeded in constructing an apparatus which floated through the air, and with which he safely lowered dogs and other animals from a balloon. But an improvement on this device was made by one M. Jacques Garnarin in 1797. Garnarin had been made prisoner after the battle of Marchiennes, and confined in the fortress of Bude, where he is supposed to have thought out a machine by which he could escape by gliding down from the window of his prison. After his release he actually constructed such a machine—a true parachute—by means of which he made many successful descents.

FIG. 5.—COCKING'S PARACHUTE DESCENT, JULY, 1837.

Up to this point the balloon had served no very useful purpose beyond affording an interesting spectacular exhibition. A decade, however, after its invention it was put to practical use by the French, who adopted it in military operations as a means of reconnoitring. Nor was this all, for in 1804, following the lead of the Russian Academy, the French organised

an ascent for philosophical research, and Gay Lussac succeeded in making valuable investigations of the higher atmosphere, thus marking another important stride in the conquest of the air.

The twenty years that next follow in the annals of aëronautics are marked by few events of consequence beyond certain sensational or foolhardy enterprises, which have no true place here. But in the early 'twenties a revival took place, and this in two opposite parts of the world. England, which had been distinctly behindhand in the development of the balloon, now produced a pioneer of future advance in the person of Charles Green, well called the "father of aëronautics" in this country. Green, duly recognising the great difficulty, expense, and uncertainty attending the employment of hydrogen gas for ballooning purposes, conceived the happy idea of using in its place ordinary coal-gas, which was now beginning to come into general use, and the true value of this idea will be apparent from the fact that, while it can be used far more easily and safely for inflation, coal-gas does not cost one-tenth part as much as hydrogen. It is scarcely too much to say that this innovation saved the balloon from oblivion, and marked the commencement of a new era in air navigation.

Green now entered on the career of a professional aëronaut, which he pursued for thirty years, during which period he made many hundred ascents without ever meeting with serious injury. Under his direction bold projects, and worthy of the enterprise of our countrymen, soon began to be mooted or embarked in. It was in the year 1836 that Mr. Robert Hollond, a young gentleman of fortune, fresh from Cambridge, conceived the idea of establishing a record by making a balloon voyage from London to the Continent. Under Green's guidance this project was safely carried out, the voyage commencing early in a November afternoon from Vauxhall Gardens, and terminating at dawn the following day at Weilburg, in the Duchy of Nassau—a distance of 500 miles accomplished in eighteen hours.

Taking advantage of the enthusiasm aroused by this bold and splendid achievement, Mr. Cocking in the following year sought and obtained the means for experimenting with a novel parachute of a cumbersome form, but of which the fatal fault was improper construction. In overconfidence the inventor attempted in this machine a lofty descent (Fig. 5), in which he lost his life, and the parachute is scarcely heard of more for half a century.

One of the eminently practical devices introduced by Green and adopted by subsequent aëronauts was the trail-rope, an appendage of some hundreds of feet long hanging beneath the car, whose function is to relieve a descending balloon of weight as it comes near the earth. Charles Green was also one of the first to produce successful working models of airships, which he exhibited to the scientific world.

Contemporary with Green, the American aëronaut, John Wise, of Lancaster, Pennsylvania, commenced a long and successful career, working on similar lines, and carrying the art of ballooning for spectacular purposes to great perfection. Among other bold exhibitions, he demonstrated how a balloon with its neck tied and caused to burst at a high altitude will form itself into a natural parachute and descend to earth probably without dangerous violence. Both Green and Wise made overtures to attempt to cross the Atlantic in suitably built balloons, but the project met with no sufficient encouragement.

Three modes of inflation have now been spoken of, each possessing distinct advantages. At the period we are now considering the hot-air system was seldom adopted, its special use being only required when coal-gas could not be easily

employed, and where hydrogen would prove too expensive. The cost of hydrogen has always been great owing to the large quantities of sulphuric acid required; moreover, the process is troublesome, and open to some risk. But these drawbacks are counterbalanced by its efficiency. In actual figures it may be stated that, whereas 1,000 cubic feet of coal-gas can be relied upon to lift about 35 lb., the same quantity of hydrogen will lift slightly over 70 lb. The fabric used for the body of balloons had up to this time generally been silk, and here again the expense was often almost prohibitory. But cheaper material began to be introduced with other improvements.

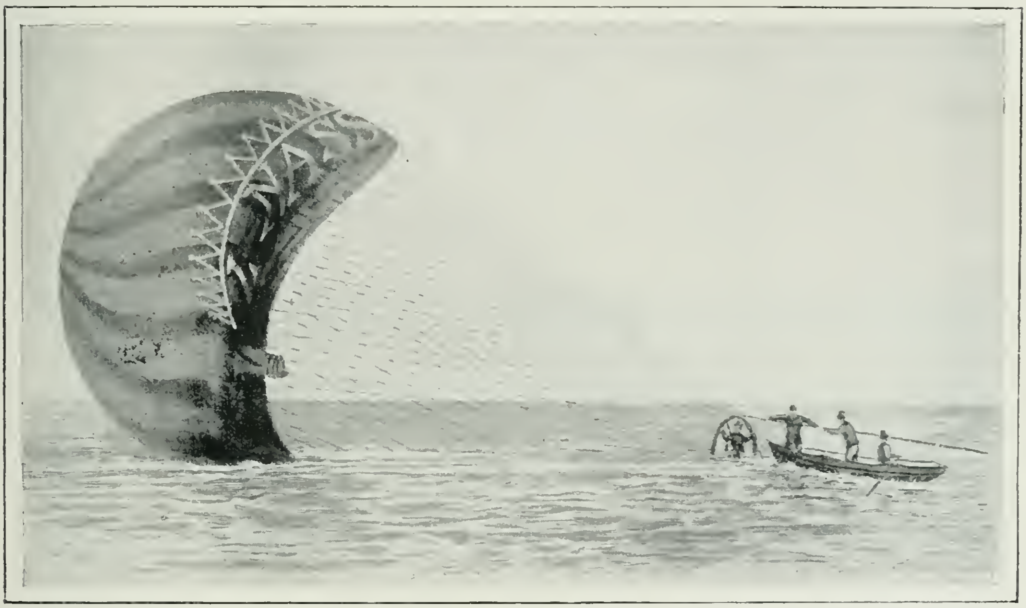


FIG. 6.—ONE OF THE PERILS OF THE NAVIGATION OF THE AIR.

Messrs. Green and Rush, who are here shown, ascended at Vauxhall on July 5th, 1850, in the great Nassau Balloon, and after reaching a height of 20,000 feet, with a temperature of 12° below freezing point, made a rapid descent. The wind was very strong, and, catching the now half-inflated balloon, blew it swiftly out to sea. Presently the car became entangled in a sunken wreck, and the progress of the balloon was stayed. The aëronauts were saved only after a perilous and exciting experience.

After an inactive period of nearly fifty years the balloon was once more brought forward as a scientific instrument, destined to contribute important knowledge by sounding the depths of air. A specially designed equipment of instruments was entrusted to Mr. John Welsh, of Kew Observatory, and four experimental voyages were made during the year 1852 under the guidance of the now veteran Green. The observations made were excellently carried out, and threw much light on the laws regulating the temperature and humidity of the atmosphere up to a height of about 23,000 feet.

A few years later the work was again resumed by Mr. James Glaisher, who made several scientific ascents under the auspices of the British Association, whose funds were drawn upon to provide the considerable sums needed to supply instruments and repair them when injured in the rough usage attending ballooning. The professional expert whose services were secured for this responsible undertaking, and whose name figures in the principal aëronautical work in England during more than thirty years, was Mr. Henry Coxwell.

Commencing life as a dentist, Coxwell developed a love for the science of

practical ballooning, which he determined to bring to greater perfection than had yet been attained, and in this it may be claimed that he succeeded. Taking the design and manufacture of balloons into his own hands, he not only became one of the most skilful of aëronauts, but originated many new developments of his art. Most of his earliest work was carried out on the Continent, where he was engaged to give public exhibitions of the variety of uses to which balloons could be devoted; on his return to England he demonstrated how they could be applied to signalling and reconnoitring in war. This was in reality a revival of the trials made by the French at the beginning of the last century, when a practical school of military aëronautics had been formed and turned to useful account in the war with Austria, as will be detailed in another paper.

Coxwell's most memorable work will, however, always be considered to be that undertaken, as already mentioned, in concert with Mr. Glaisher. All these voyages were marked by great boldness, and gave proof of consummate skill on the part of the aëronaut. In the first ascent—which was in July, 1862—no less an altitude than 25,000 feet was attained, and considerable inconveniences were felt in the attenuated atmosphere. This altitude was far eclipsed a short while after, when, in the desire to reach an extreme elevation, Mr. Glaisher became paralysed and insensible, and was only revived by a prompt descent which Mr. Coxwell effected, but, owing to exhaustion, only with great difficulty. The actual height attained on this occasion must remain problematical, owing to the chief observer being rendered incapable of taking the final observations. A calculation was made which put the height at 36,000 feet at least, but, in considering this, it must always be remembered that no modern aëronauts have succeeded in reaching that excessive altitude, even with the assistance of oxygen gas and other restoratives.

A good idea of the nature of the results obtained during these classical aërial researches into the dominion of the air may be gathered from the following account compiled on a typical day in summer. "In ten seconds they were in mist, and in ten seconds more were level with the cloud. At 1,200 feet they were out of the rain, though not yet out of the cloud. Emerging from the lower cloud at 2,300 feet, they saw an upper stratum of dark cloud above. Then they made excursions up and down, trying high and low to verify these conditions, and passing through fogs, both wet and dry, at last drifted earthward through squalls of wind and rain, with drops as large as fourpenny pieces, to find that on the ground heavy wet had been ceaselessly falling."

At the time when Coxwell retired from the active career of a professional aëronaut, the attempts of mankind to conquer the realm of the air by balloon already dated back for one hundred years; and, while vast successes had been gained, it may be accounted alike a wonderful and instructive fact that fatal accidents had been extremely few and, in this respect, out of all proportion to the progress that had been made. Ballooning properly undertaken was not attended with undue risk to life, and claimed far fewer victims than many another calling. The principal recognised danger was connected with the descent, which might take place on undesirable ground, or which through a variety of causes might be subject to limited control. Yet even under conditions seemingly appalling, the danger had been proved to be more apparent than real. Messrs. Glaisher and Coxwell relate how, on one occasion, a fall to earth at speed so terrific that a descent of one mile occupied only two minutes was attended with no more rough

usage than a few bruises; and other voyagers have had similar experiences to tell. The explanation of this lies in the fact that the neck of the balloon, if unrestrained, will form itself into a hollow to catch the air, much as does a parachute, and thus speed is checked, while the elasticity of a wicker basket will greatly lessen the shock which direct impact with any hardened surface of earth would otherwise give.

A perfectly reliable valve, and one that is under due control at the crown of the balloon, is a desideratum, as also is a sufficient reserve of ballast in the shape of bags of sifted sand. The balloon itself is unavoidably subjected to many vicissitudes as it floats through space. Chilling of the gas, or its mere slow leakage into the air, will cause the vessel to descend; and, on the other hand, the action of warm sun on the great globe may cause the gas to expand, and give the balloon an upward tendency. It will be readily understood that ascent, if undesirable, can be checked by the liberation of gas through the valve, while to prevent or retard descent it generally suffices to empty out a certain quantity of sand, which, scattering as it falls, reaches the ground without the slightest element of danger to anybody.

FIG. 7.—THE CITY OF LONDON AS SEEN FROM A BALLOON.

CHEESE.

By C. W. WALKER-TISDALE,

Lecturer in Dairy Farming and Dairy Bacteriology at University College, Reading.

THE conversion of milk into cheese seems to have been the first method discovered for preserving the nutritious constituents of milk in the form of a concentrated food material. From the earliest times we read of cheese being used as an article of diet, and now that we have come to understand what it is composed of, and the science of its production, we can easily understand this, for we shall find that it is one of the most nutritious of all the foods consumed by man (*see* Fig. 1).

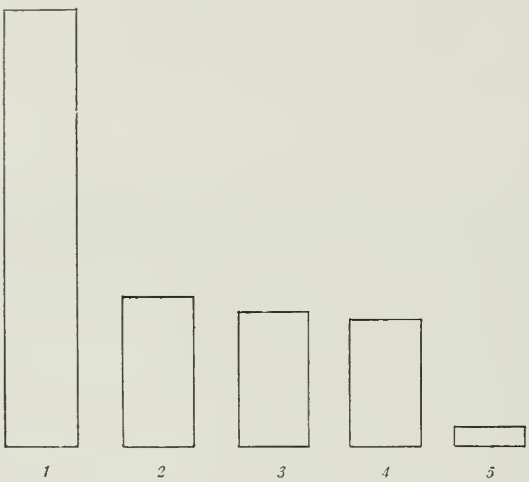


FIG. 1.—THE CONSTITUENTS OF CHEDDAR CHEESE.
1, 100 parts of cheese; 2, water - 34 parts; 3, fat—31·3 parts; 4, casein, etc.—30·6 parts; 5, ash—3·9 parts.

Generally speaking, cheese is manufactured from the milk of the cow, and contains all the constituents naturally present in it. The milk of the goat and sheep is also used for cheese-making, but not in this country. For example, the famous Roquefort cheese produced in France is the product of sheep's milk, though at the present time—owing to the large demand—a great quantity is made from cow's milk, and so an imitation is palmed off as the genuine article. Goat's-milk cheese is not an important article of commerce. Besides cheeses made from whole milk, we have a number of varieties of a much poorer character manufactured from skimmed and even separated milk, which are usually hard and wanting in mellowness, owing to the lack of fat in their composition. The lack of cream or fat in the separated milk is sometimes made up for by the addition of margarine, and hence the product known as *filled* or *margarine* cheese, which at best is a wretched imitation of even ordinary well-made skimmed-milk cheese; and further, *whey* cheese, made from the whey of either cow's or goat's milk, an article in demand in some countries, chiefly in Norway. On the other hand, there are cheeses which are much richer than those made from whole milk. They may be made solely from cream, or, again, manufactured from milk to which a quantity of cream has been added. The latter, however, are few in number at the present time; and although it is popularly believed that Stilton is a cheese to which cream has been added, this is not really the case.

Now although the consumption of cheese amongst all classes in this country is increasing annually to a very considerable extent, the man in the street knows very little about the different varieties and how they are produced. The cheese trade in London is now a very important one—indeed, it would astonish the average Britisher to know the huge sums of money paid by us for the fancy varieties of Continental cheeses

imported, the sale of which in London and the south of England generally proves a mine of wealth to the French.

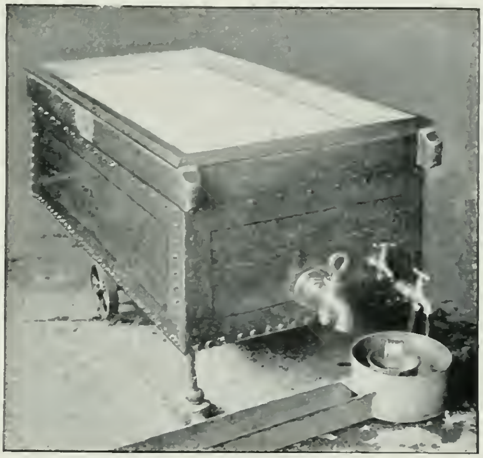


FIG. 2.—THE FIRST STAGE IN CHEESE-MAKING: MILK IN JACKETED VAT READY FOR RENNETING.

There are about twenty distinct varieties of British cheese manufactured, but, of the 13 lb. per head per annum consumed by the Britisher, 7 lb. is imported. In classifying cheeses we find

FIG. 3.—CURD UPON COOLER.
The curd is placed in cloths, and is laid upon wooden racks which, in their turn, rest upon a tinned iron tray.

that they will all come under the three following headings:—

(1) *Hard-pressed cheese* is exposed to a considerable amount of pressure during manufacture. Examples are Cheddar, Cheshire, Leicester, Derby, Single and Double Gloucester, and Caerphilly.

(2) *Blue-veined cheese* is not pressed at all, or, if pressed, does not receive very heavy pressure. Examples are Stilton, Wensleydale, Dorset Blue, and Gorgonzola.

(3) *Soft cheese* is soft in consistency, and there is a large percentage of water present in the finished article. Examples are York, Cream, Pont l'Evêque, Coulommies, Gervais, and Brie.

In the following table will be found

the composition of some of the most important varieties of cheese. With English-speaking people Cheddar (*see* Fig. 1) is the type most largely manufactured and consumed.

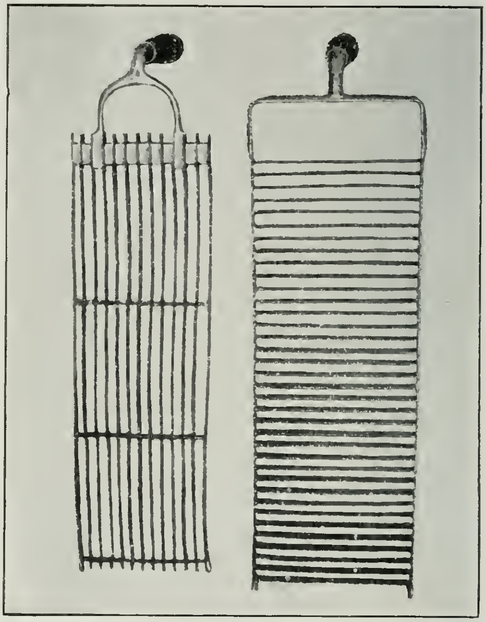
It is not necessary to further explain the table, as in the article on "Milk," Vol. I., p. 124, full particulars were given as to the feeding value, etc., of the different constituents of which milk is composed, and the constituents which build up cheese are the same as those of milk.

PERCENTAGE COMPOSITION OF DIFFERENT VARIETIES OF CHEESE.

(McConnell.)

	Water.	Casein.	Fat.	Sugar and Lactic Acid.	Ash.
British (Hard)—					
Pressed—					
Cheshire (Ripe) ...	32·59	32·51	26·06	4·53	4·31
Derby...	31·68	24·50	35·20	4·38	4·24
Leicester	32·89	29·06	29 28	4·42	4 35
Wilts loaf	34·44	29·00	28·71	3·60	4·25
Gloucester (single) ...	32·50	28·51	28·23	2·85	4·66
Do. (double)...	35·96	21·74	26·83	2·23	4·07
Skim milk	45·39	33·12	9·97	6·39	5·13
Unpressed—					
Stilton...	30·35	28·85	35 30	—	3·82
Cotherstone	38·28	23·93	30·89	3·70	3 20
British (Soft)—					
Cream...	30·65	4·94	62·99	—	1·15
French (Hard)—					
Gruyère or Emmenthal	34·87	25·87	28·01	—	3·84
Cantal...	44·2	25·70	24·00	—	—
Roquefort	31·20	27·63	33·16	—	6·01
French (Soft)—					
Brie	50·35	17·18	25·12	—	5·41
Camembert	50·16	21·85	21·13	—	3·89
Gervais (made from milk to which one-third cream is added)	52·94	11·80	29·75	2·58	2·93
Neufchâtel or Bondon	44·47	14·60	33·70	—	2·99
Dutch—					
Edam (round)	36·28	24·06	30·26	—	4·00
Gouda (flat)	21·90	46·95	24·81	—	6·32
Italian—					
Gorgonzola	44·04	28·06	29·84	—	3·87
Parmesan	31·34	41·90	10·22	—	6·25

Within the last few years very great changes have come over the cheese-making industry. The old rule-of-thumb methods are giving way to scientific ones, and the dairy scientist is able to advise the practical cheese-maker on points of difficulty which before he only overcame through luck, if he ever overcame them at all. Bacteriology is the science which has proved the most helpful, for if only its teachings have shown the dairyer the great necessity for cleanliness in all the operations, a great and lasting good has been accomplished. It is not meant here to indicate that the



A *B*

FIG. 4.—AMERICAN CHEESE CURD KNIVES.

A has vertical, and B horizontal cutters. The operator in Fig 5 is using one of these knives.

cheese-maker is naturally wanting in cleanliness, but to show rather the importance of protecting milk from the sources of contamination with which it is so liable to come into contact.

If we get the wrong kind of bacteria in the milk, to begin with, it is almost an impossibilty to turn out a cheese of first quality. Just as an illustration we may take the case of cows wading in stagnant, muddy water in summer time. The water with its sediment dries on the udder and flanks, and when a careless

milker comes to milk the cow he disturbs much of this filth with his hands and arms, so that it finds its way with the milk into the pail.

The consequence of this is that the milk becomes inoculated with a large quantity of harmful micro-organisms, which multiply very rapidly in the warm milk, the curd and cheese developing peculiarities, such as ill smell and flavour, sometimes becoming filled with gas, and even blown out into a shapeless mass after being taken from the mould. Cleanliness, then, is the first and most vital principle taught by dairy bacteriology.

Milk as present in the cow's udder is not entirely free from bacteria, as is often stated; the first portions, or *fore* milk, when drawn, may be shown to contain fairly large numbers, but the milk taken after the first streams have been drawn off is entirely free from micro-organisms.

In cheese-making the great object throughout is to cultivate the lactic acid bacteria—at least, this is what the teachings of science have so far revealed to us. Now, lactic acid bacteria usually predominate in milk, and are responsible for its souring; therefore, if they are present in excess of the obnoxious germs, all is well. If, however, the lactic germs are weak or few in number, the bad bacteria gain the upper hand, with the result that inferior produce is inevitable. We now use lactic acid bacteria in the form of a *starter*, or sour whey, which is added to the milk at the commencement in a similar manner that we use these bacteria for the purpose of cream ripening (*vide* "Butter," Vol. I., p. 318). This gives us a more ready control of operations, for whereas formerly we were dependent upon the bacteria present in the milk for the fermentation, now it is possible to supply the milk with the desired organisms in the quantities required, and so the process is made a more exact one.

FIG. 5.—CUTTING THE CURD.

This is necessary in order to get rid of the whey. The curd is cut into cubes of about a quarter of an inch.

Of the number of cheeses that are

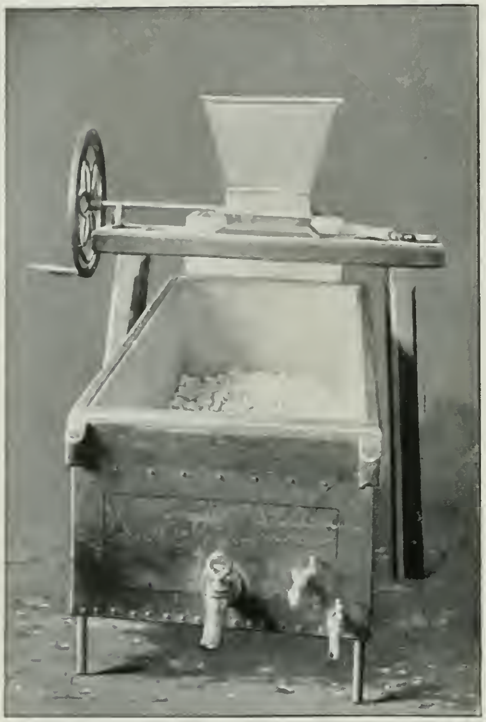


FIG. 6.—CURD MILL, SHOWING GROUND CURD IN THE VAT.

In the manufacture of any variety of hard-pressed cheese — for example, Cheddar—the milk is warmed to a temperature varying between 80° and 90° F., and averaging about 84° F. On attaining this temperature it is tested for acidity, as it is essential that it should contain an appreciable amount of acid equal to about ·22 per cent., calculated as lactic acid. The testing may be done in different ways. The old-fashioned dairyman still uses the senses to determine the fitness or otherwise of the milk, taste and smell being largely and strangely developed in this individual. More accurate means are the rennet test and the *acidimeter* (Fig. 8), the latter being a laboratory test first applied to cheese-making by Professor F. J. Lloyd, and now used by most up-to-date cheese-makers. The test is simple and accurate in the hands of any person of average common sense. It consists of taking 10 c.c. of the milk or whey to be tested, adding two or three drops of *phenol*

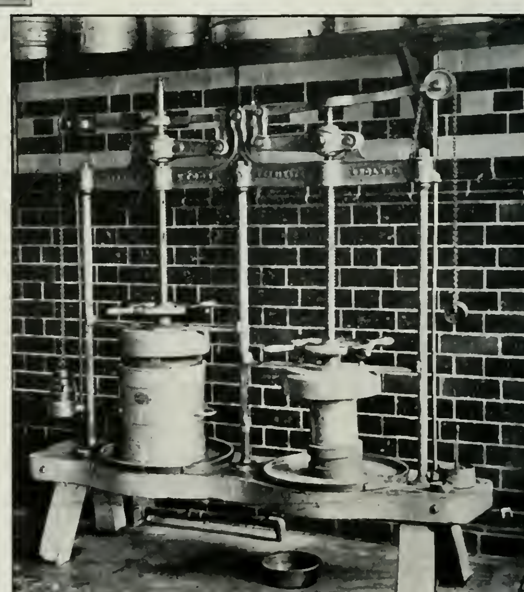


FIG. 7.—A DOUBLE CHEESE PRESS.

By means of this contrivance a pressure of one and a half tons may be put upon the cheese. This extracts the remnants of the whey.

made it is only in the case of a few that the science underlying the process of making and ripening is really understood. For instance, Cheddar is the one which is best understood, and, on account of its universal production, it has been the object of much investigation in this country by Professor F. J. Lloyd, whose report on eight years' experiments, issued by the Board of Agriculture, is worthy of being studied by all cheese-makers.

Of many other varieties of British cheese our knowledge is very limited, especially of Stilton, that famous product of the counties of Leicester, Stafford, and Derby. This variety, although commanding the top price of all the British brands, is still made in various ways not comprehended; each maker has his own particular mode of treating the curd.

phthalein to act as indicator, and then titrating with alkali of known strength until a pink tinge appears in the milk. The amount of alkali taken to neutralise the acid is read off on the *burette*, and its equivalent in terms of lactic acid is at once known.

The rennet test is dependent upon and registers the acidity of the milk. A given quantity—4 oz. of milk at 84° F.—is taken, and 1 dram of rennet added to it. The time taken in coagulation, which may be from sixteen to thirty seconds, is noted, the shorter the time the riper or more acid being the milk, and *vice versâ*.

On ascertaining the acidity the cheese-maker is in a position to know if the milk is ready for renneting (Fig. 2); if not acid enough, it may be kept warm for an hour or so, during which time the bacteria develop and increase the acidity. It is at this stage that pure cultures of bacteria or starters are added, the amount used being inversely proportional to the acidity of the milk; if the milk is very sweet a large quantity is needed, otherwise the cheese may take an extremely long time in manufacture. The rennet now generally used consists of the concentrated prepared extracts, one part being capable of coagulating some 10,000 parts of milk. The home-made rennet made by soaking the vell—which is the fourth or digestive stomach of the calf—in salt water is

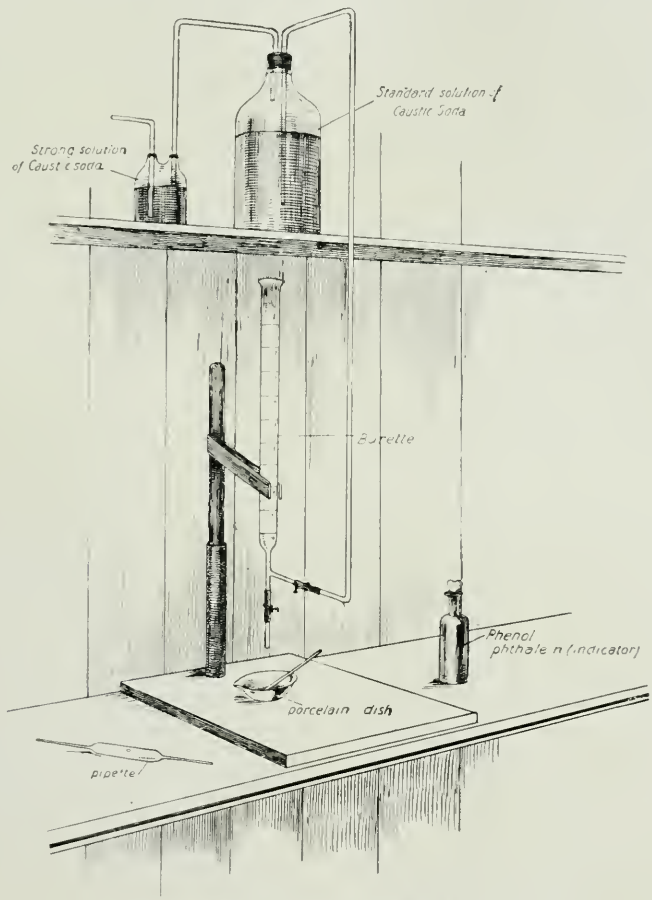


FIG. 8.—ACIDIMETER FOR TESTING THE AMOUNT OF ACID IN MILK AND WHEY.

not now much used, except by the Stilton cheese-maker.

Rennet in the proportion of 1 dram of extract diluted with water to every

FIG. 9.—BLUE MOULD *(PENICILLIUM GLAUCUM)* WHICH GIVES THE VEINING SO MUCH DESIRED IN STILTON AND GORGONZOLA CHEESES.

3 gallons of milk having been added and well stirred in for five minutes, coagulation is allowed to take place, and this occupies forty-five to sixty minutes. At the end of this time American curd knives (Fig. 4) are used to cut the curd into small cubes of about a quarter of an inch in size (Fig. 5). This operation must be performed carefully to avoid loss of fat in the whey, which at this stage separates from the solid portion or curd.

The curd is now stirred gently in the whey for fifteen or twenty minutes, and then the whole contents of the vat are gradually heated up to 96°–102° F. This cooking process favours the production of acid, and the heating, together with the acidity, makes the curd firm, so that by the time the whey is drawn off it is elastic. From this time onward the curd is matted together, kept warm, and occasionally opened out and cut up. When the drainings from the curd register about ·8 per cent. of acid, the curd is ground up in a mill (Fig. 6), salt is added at the rate of 2½ per cent., and the whole placed in mould and put to press (Fig. 7). At this stage the curd is hard and leathery, and quite indigestible. The pressure is continued for three days, being very light for the first few hours, then being gradually increased to from 20 cwt. to 30 cwt. By the time the cheese is put to press acidity is checked. The whey has been squeezed out, and this contains most of the sugar which the bacteria convert into lactic acid. On removal from the press the cheese, after being bandaged, is taken to the ripening room, where it remains about three months, until it is ripe.

The manufacture of a soft cheese is quite different.

(1) The aim is to get a soft and tender curd, so that perfectly new sweet milk

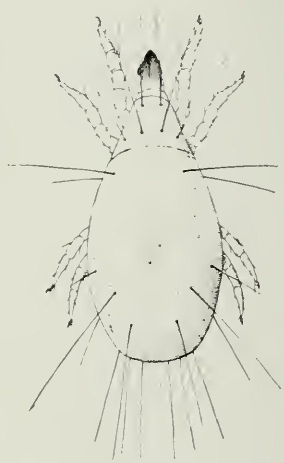


FIG. 10.—CHEESE MITE *(ACARUS SIRO)* AS SEEN UNDER THE MICROSCOPE.

is used, as acidity promotes the action of rennet.

(2) A fairly low temperature and a minimum amount of rennet are employed; this means that coagulation is prolonged, and a soft curd results.

(3) The curd is not cut into small

pieces, but is sliced out with a ladle and placed directly in the moulds.

(4) The whey drains off naturally from the curd, and some moisture is also lost by evaporation, but in the finished cheese a high proportion of water still remains.

We come now to the after treatment or ripening of the different classes of cheese, which is perhaps the most important, as certainly it is one of the most interesting, parts of cheese-making. This ripening is due to the growth and activity of bacteria and moulds. Let us consider the ripening of a soft cheese like "Camembert." Fresh Camembert is very acid in reaction. A few days after making there will be seen to appear on the outside a white mould, which a few days later will have changed to a dark blue-green colour. This blue mould is a species of *Penicillium*, recently described as *Penicillium candidum*, and with the growth of this and other moulds, which may be present, but not necessary, the acid condition of the cheese disappears.

When the mould dies down, the bacteria begin to work, beginning at the outside and gradually spreading to the interior. The reddish-yellow colonies of bacteria responsible for this work show two distinct micro-organisms, the function of one being to carry on the work of converting the insoluble curd into a soluble condition, whereas the other prevents too much liquefaction from taking place. If there is present too much of the former the cheese "runs"; if too much of the latter, it does not ripen properly.

In the ripening of blue-veined cheese such as Stilton and Gorgonzola the gradual development of the mould *Penicillium glaucum* (Fig. 9) gives the blue veining so much desired. The spores of this fungus gain entrance to the curd from the atmosphere before the former is placed in the moulds, and the cheese being of open texture, and unpressed, allows of the presence of a sufficiency of air for their development.

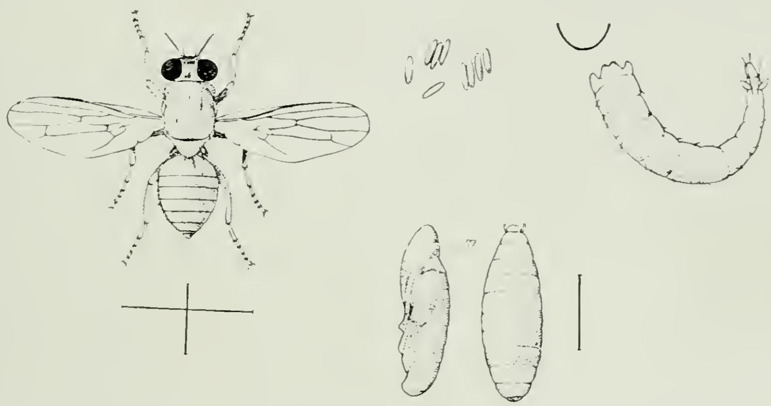


FIG. II.—CHEESE FLY *(PIOPHILA CASEI)* WITH EGGS, LARVÆ, AND PUPÆ.

This fly is a small, black, glistening insect about $\frac{3}{16}$ in. in length. It likes a moist cheese. The eggs hatch in from 36 hours to 4 days, and give rise to the maggots known as "cheese skippers." The "skipper" feeds for some 15 days, and then turns into a golden brown pupa. The pupa stage lasts about 10 days.

The ripening of Cheddar is not necessarily accompanied by the growth of moulds. Ripening is due to the further development of lactic acid bacteria, and not to butyric acid organisms, as formerly believed; indeed, the ripening process is very similar to the digestion of food. The casein is gradually changed into soluble nitrogenous substances.

The American school claim that an enzyme called *Galactase*, naturally present in milk, is largely responsible for the

production of the soluble albuminoids present.

The temperature at which Cheddar is usually ripened is about 60° F. A cheese is fully matured in three months, and should keep for many months in perfect condition.

Amongst pests may be mentioned the "cheese-mite," *Acarus Siro* (Fig. 10), which very readily attacks cheese of a dry character, especially where there are cracks or crevices in the rind.

Stilton cheese, in particular, will always be found covered with a number of these tiny creatures, which appear upon it as a brown dust.

Then there are certain flies which are specialists in cheese, the cheese fly, *Piophila Casei* (Fig. 11), being the worst offender. This fly favours a moist cheese, and there lays its eggs, which in from thirty-six hours to four days hatch out into the maggots known as "cheese skippers," and bore right into the heart of the cheese. After feeding on the cheese for a week to fifteen days they turn into golden brown pupæ, which in a further ten days or thereabouts hatch into the mature flies. As many as three generations are produced during the year, so the supply of "cheese skippers" is not likely to run short.

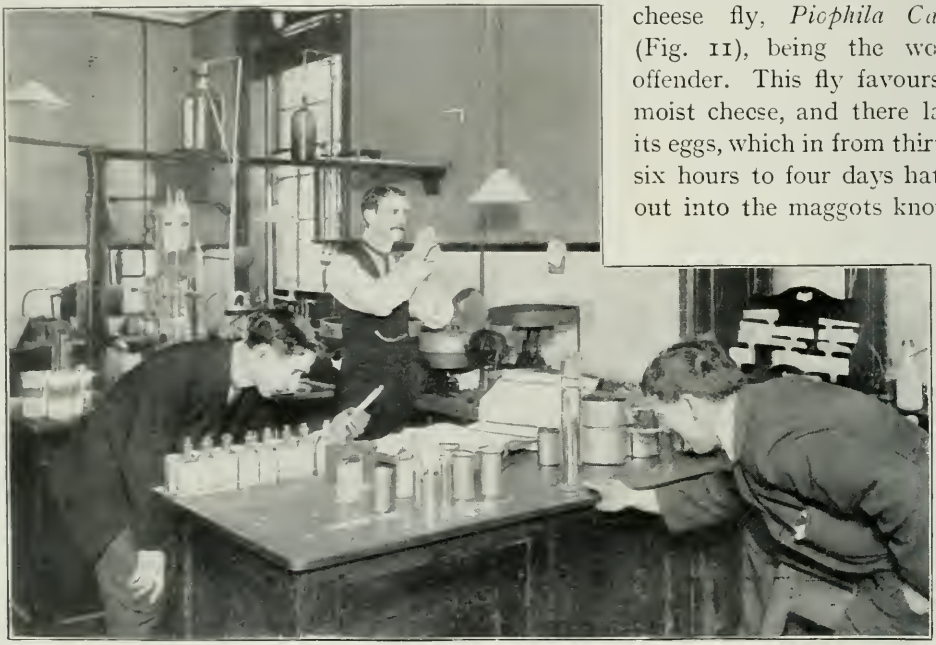


Photo: Cassell & Co., Ltd.

FIG. 12.—AT WORK IN THE LABORATORY (AYLESBURY DAIRY COMPANY).

A WINDY SUNSET.

A STREAKY SKY OF THIS KIND. WITH FLEECY WISPS OF CLOUDS SCATTERED ABOUT, IS ALMOST A SURF FORERUNNER OF WIND, WHICH MAY OR MAY NOT BE ACCOMPANIED BY RAIN

WHY THE WIND BLOWS.

THE winds that blow over the surface of the earth have all a different origin, and, although there is a family likeness, each has its own individuality. For convenience of reference the winds may be divided into three classes, for they are either *permanent*, *periodic*, or *variable*. As illustrating the first division the Trade Winds may be mentioned, the Monsoons serving as an example of the second, the winds that blow in the British Isles being representative of the third. In the class of variable winds, moreover, such winds as the familiar land and sea breezes are to be included—winds that are typical of others that rise in all parts of the world.

Now, in order to gain a clear understanding as to why the wind blows, it is necessary to think first of the manner in which the atmosphere as a whole is circulated, for the winds, no matter to what class they belong, derive their main impulses and characteristics from these larger currents of air. Primarily all winds are born of the great ascensional currents of air that rise at the Equator and flow away towards the Poles. All winds, of course, have certain features in common, but in all cases the chief impelling force is a rising current that displaces a large mass of air, the vacancy thus created being filled up by air that flows inwards from surrounding areas. Supposing, therefore, that the lower strata of the earth's atmosphere be considered to be about seven miles high, or about 35,000 feet thick, it will be understood that no movement would take place in the air unless its density were altered by changing its temperature. There is, however, a large difference between the mean annual temperature at the Poles and at the Equator that amounts to between 70° and 80°. As a result, the atmosphere over the Equator stands at a much higher level than it does over the Poles. There is, indeed, an enormous atmospheric slope, as it may be described, from the one region to the other—a slope that is mainly responsible for setting the air in motion. It has been calculated that the difference between the height of the atmosphere at the Equator and the North Pole is 2,800 feet, and at the South Pole 3,150 feet. Such figures are, at best, but a rough estimate, but they serve to emphasise the importance of this atmospheric slope down which the atmosphere slips on its way to the Poles. From these latter regions there are, of course, return currents or winds that by devious ways find their way back to the Equator again.

Broadly speaking, this is the ground plan of the winds, but the causes acting on it are countless, so that it often becomes obscured. Thus, the upper winds flowing from the Equator do not all of them complete the journey to the Poles, for at about latitude 30° some of them descend towards the ground. By so doing they are caught by the atmospheric current flowing at the surface of the earth, and as a result they return towards the Equator. These winds are the famous Trade Winds. Now it should here be called to mind that, owing to the rotation of the earth, all objects moving across its surface are liable to be deflected out of their course. In latitude 50°, for example, a bullet moving at the rate of 1,700 feet a second and aimed at a target 3,300 feet distant, would be turned aside to the extent of four inches to the left of the target in the southern hemisphere,

and there would be an equal deviation to the right in the northern hemisphere. A similar thing happens to the Trade Winds, so that in the northern hemisphere they go to the right and become the north-east trades, and to the left in the southern hemisphere, where they become the south-east trades. This deflective force is at work on all winds, and is a factor that needs to be given a prominent place when seeking to learn why the wind blows.

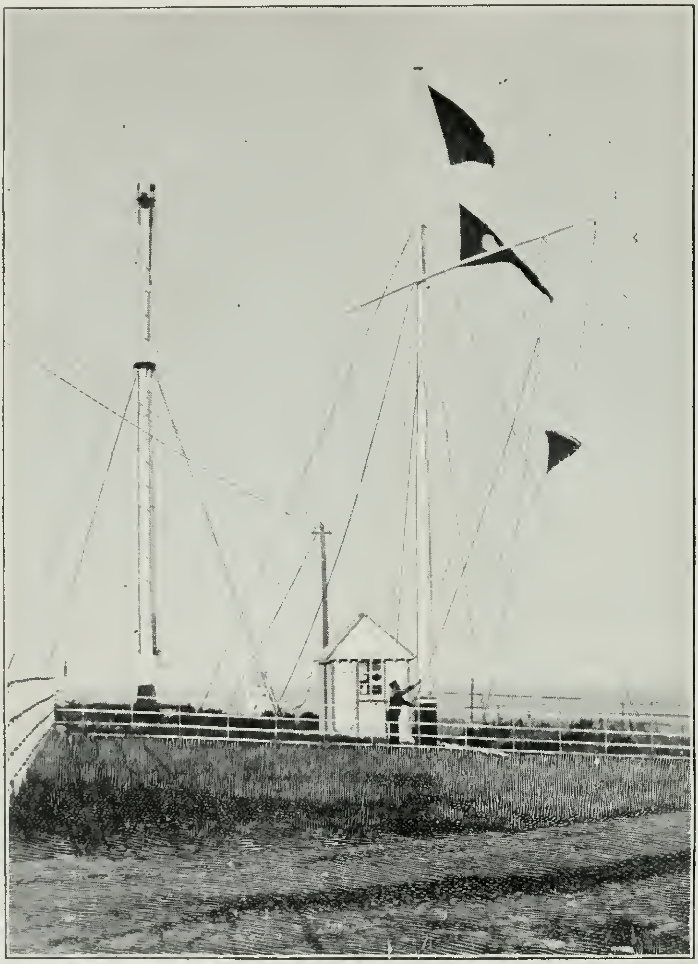


FIG. I.—HOISTING STORM SIGNALS AT THE NORTH FORELAND.

Having thus glanced at the forces that produce the great permanent winds of the earth, such as the Trade Winds and the Equatorial and Polar currents, the next class of winds for reference are those sometimes called periodic. Of these, as already mentioned, the Monsoons are probably the most familiar. Between these winds, moreover, and the equally familiar land and sea breezes there is a great similarity, only one is on a much larger scale than the other.

Now during the day the land grows much hotter than the sea, so that the air over the one surface stands at a higher level than it does over the other, with the result that there is an atmospheric slope from the land to the sea. This slope, as was seen to be the case with the great

Equatorial currents, affords an easy path for the currents of air, which slip, as it were, from over the land out to sea. Over this latter area the atmospheric pressure is thereby greatly increased, and as a result a current of air sets in from the sea towards the land, and is known as the sea breeze. On the other hand, during the night the air over the sea is warmer than it is over the land, for this latter surface has been greatly cooled by radiation. The atmospheric slope is now from the sea towards the land, the effect being to cause a current of air that is pushed out from the land towards the sea, thus producing a land breeze.

These general principles may be applied to winds in numerous localities, and it will be found that they explain many of the local breezes observed in all parts of the world. As already stated, these principles may be traced in such winds as the Monsoons. In this case, differences of atmospheric pressure are produced by the seasonal variations that occur as regards the temperature of the Indian plateau and the surrounding sea. The Monsoons, indeed, are but land and sea breezes moving up and down an enormous atmospheric slope.

Further, in order to gain clearer conceptions as to why the wind blows, it is of interest to consider the Föhn Winds, that are also typical of a very large class. Commonly winds of this type occur in mountainous regions, and gain their main impulses from the currents of warm, moist air that flow against the sides of the mountains. In these circumstances the cold sides of the mountain reduce the temperature of the air, so that the latter immediately condenses some of its moisture. But condensation of moisture means the liberation of latent heat that in such cases often appears in enormous quantities. This heat goes to raise the temperature of the air currents flowing up the sides of the mountains, so that by the time the winds reach the mountain tops they are not so cold as they otherwise would have been, or, as the meteorologist would say, the dynamic cooling has been greatly retarded. Now when such a wind commences to flow downwards into the valleys beyond, it starts not only as a warm wind but also as a very dry one. Moreover, as soon as it moves downwards, the pressure—which steadily increases—raises the temperature of the wind. By the time, therefore, that such a wind reaches the lower levels and passes into some of the valleys, it blows in hot, strong blasts, and oftentimes with great violence. These Föhn winds occur in many of the Swiss valleys, and the precautions that are taken to guard against fire when such winds are rushing through the villages—the houses wherein are commonly built entirely of wood—are sufficient evidence of their destructive violence. As with the winds previously mentioned, the principles underlying the Föhn winds may be applied elsewhere, and by so doing the origin of many curious air currents will be revealed.

Something of the processes that set the air in motion may also be elucidated by making a few experiments. Thus, the invisible air which floats everywhere about the solid bodies standing upon the earth, and which rests upon the water and the ground, has weight, and is drawn by terrestrial attraction after the same manner as water or lead, although its substance cannot be seen. A pint bottle, which seems to be empty, in reality contains 11 grains of air. The same bottle would hold something more than 9,000 grains of water if water were poured into it in the place of air. Air is therefore 820 times lighter than water. Water can be poured into a bottle that was previously filled with air, because the water is heavier than the air. The water goes down in consequence of its greater weight, and drives the air up out of its way.

A familiar proof of the ponderous substantiality of this unseen and unseeable air is that which everybody experiences every day without taking any notice of it, until the attention is specially drawn to the matter. Like all other substances which possess weight, the invisible air *pushes* against bodies that stand in its way when it is moving. It rushes against the face so that it can be felt. It turns the sloping mill-sails round when it drives against them, if travelling itself with sufficiently impetuous speed. It forces the sailing ship to glide along over the sea when it strikes upon the broad canvas sails that are spread to catch the impulse.

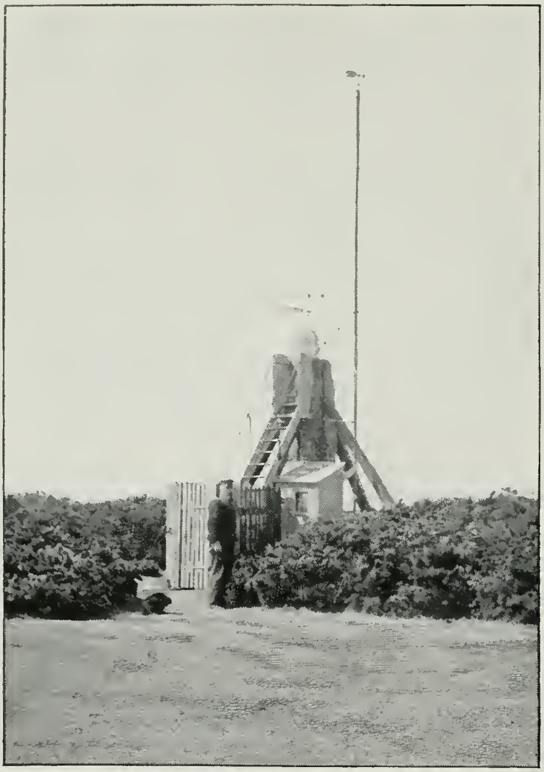


FIG. 2.—AN ANEMOMETER, OR WIND GAUGE, AT ST. MARY'S, SCILLY ISLANDS.

But the minute particles of the invisible air, which are substantial enough to produce these very obvious mechanical effects, do not touch each other, as they exist in their natural condition in space. They float, in their inscrutable minuteness, certainly many times their own diameters apart. They may be driven to approach a little nearer together by the exertion of external compressing force, but they cannot be squeezed into contact by any power that man can bring into play for the purpose. They are not forced into contact by any of the incalculably greater powers that Nature herself deals with in her own majestic and mighty operations. They constantly stream and roll about amongst each other in all conceivable directions. Science, indeed, teaches that in all probability they are in perpetual unrest, and unceasingly rushing about amongst themselves, and that when 11 grains of air-particles are corked up in a glass bottle, notwithstanding their apparent stillness, they occupy themselves with a never-ending dance during their forced imprisonment, each particle dashing from side to side and to and fro, and never pausing an instant in its headlong and mad career, although it has all the time to wheel itself out and in and round its companion particles, to avoid coming into collision with them. Such is what science has, up to this time, been able to ascertain and to conceive in reference to the molecular constitution of air.

But, although air is so light that the quantity which fills a pint bottle, and which occupies 35 cubic inches of space, does not weigh more than a piece of card of the size of the figure which is here sketched (Fig. 3), its weight nevertheless becomes a very important affair when large quantities have to be taken into

account. The air stretches everywhere about the earth, and folds it all round, and extends out into space a very con-

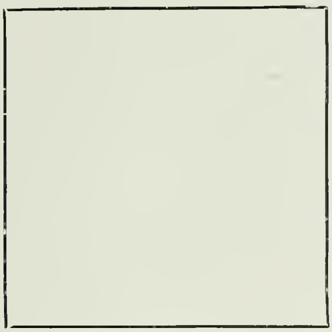


FIG. 3.—PIECE OF CARD, TO INDICATE WEIGHT OF AIR OCCUPYING 35 CUBIC INCHES.

siderable distance away from the surface of the ground. No one yet knows exactly how far it reaches, because no one has yet been able to get far enough out to ascertain where it ends. But it certainly spreads more than fifty miles from the solid surface of the earth and from

FIG. 4.—ILLUSTRATING TORRICELLI'S EXPERIMENT TO DEMONSTRATE THE PRESSURE OF THE ATMOSPHERE.

This tube, which is a little more than 30 in. long, is filled with mercury, and inverted in a basin filled with the same "liquid," as shown in Fig. 5.

the liquid surface of the sea. The quantity, therefore, that rests upon an acre of ground, in consequence of this, presses down upon that space with a weight of no less than 22,000 tons! Fifteen pounds of it are sustained upon each square inch of the land that is near the level of the sea. This height of the invisible air was first ascertained at Florence, in the year 1643, by the Italian philosopher Evangelista Torricelli. He took a glass tube which was a little more than 30 inches long and open only at one end (Fig. 4). Then, holding the tube perpendicularly, with the mouth upwards, he filled it with mercury, and placing his finger over the open end,

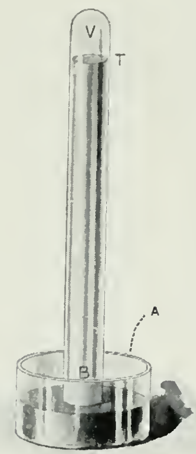


FIG. 5.—THE MERCURY TUBE INVERTED.

The pressure of the atmosphere is sufficient to sustain the weight of a column of mercury 760 millimetres (30 in.) long. This is the fundamental principle of all mercurial barometers.

turned it upside down, so that he could plunge the mouth into mercury held in a broad basin or cistern (Fig. 5). He then found that the mercury contained in the tube fell a little way until it rested about 30 inches above the level of the cistern, and there stopped, leaving a small, altogether empty space in the tube above its top. It was shortly afterwards shown, either by Torricelli or by Pascal, that the 30 inches of mercury were kept up in the tube by the weight of the air which pressed down upon the surface of the mercury in the cistern outside of the

tube. The air was pressing down upon the mercury outside the tube at A, and the mercury, without any air, was pressing down upon the same liquid mass at the bottom of the tube at B, and the two exactly balanced each other by their opposing pressures, when the column of mercury in the tube came to rest at T, leaving the entirely empty space V above it. The column of air, which went up more than 50 *miles* on the one side, was exactly of the same weight as the column of mercury which went up, on the other, 30 *inches* into the tube. By repeating the experiment with a tube that contained a cross area, or section, equal to a square inch, he afterwards found that it required just 15 lb. of mercury in the tube to resist or balance the antagonistic column of air, and he was thus able to show that a square column of air of the same size, or 1 inch across, and extending to the utmost limit of the atmosphere, weighed 15 lb. It was this experiment, first contrived by Torricelli, which led to the construction of the instrument called the "Barometer," or "measurer of weight"—that is, measurer of the weight of the atmosphere. In recent years the barometer has been made in a great variety of forms, but for accurate work it is desirable that the instrument be as simple in construction as possible.

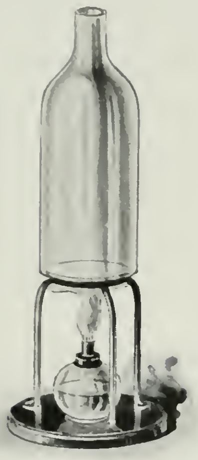


FIG. 6.—HEATED AIR EXPANDS.

But any given bulk of air is not always of the same weight. An inch-square column of the atmosphere sometimes weighs more than it does at others. This, therefore, is why the mercurial column of the barometer, which is the counterpoise of the equivalent column of the air, goes up and down from day to day within the glass tube of the instrument. The cause of this change of weight, however, is quite understood, and can be very easily explained. It is due to the fact that the little invisible particles of the air sometimes lie more closely together than they do at others—or, in other words, that any given bulk of air—such as a cubic foot—sometimes contains a greater number of air-particles in it than it does at others.

This effect can be produced by mechanical pressure. Air under particular management, can be actually squeezed in, so as to be made to occupy less space. The operation would, of course, make the air specifically denser than it was before. That is to say, a cubic foot of compressed air would weigh more than a similar quantity not subjected to the pressure. There are, however, other means by which the same result can be brought about. Cold, for instance, will do the same thing as compression. Imagine the case of 11 grains of air, possessing the ordinary summer temperature of 70°, being poured into a pint bottle, and the bottle being then surrounded outside by ice, while it is still left uncorked at the neck. This is what would then happen: The air inside the bottle would be made cold by the ice, and as it gradually became more and more cold, its little particles would be drawn more closely together, and so its entire mass or bulk would contract. But, as it did this, more

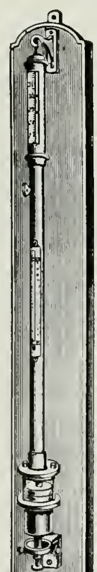


FIG. 7.—BAROMETER CONSTRUCTED ON THE FORTIN PRINCIPLE.

air-particles would necessarily flow in through the open neck of the bottle, until at last it would be found that the bottle contained more than 11 grains of air, although its size had not been materially changed. In other words, the pint of air would have become heavier. If, then, the bottle were taken away from the ice, and placed over the flame of a spirit-lamp, as represented in Fig. 6, the air would become hotter and hotter minute by minute, and, as it did so, its little particles would be driven further and further asunder, so that many of them would be forced to rush away out of the neck of the bottle, until finally the bottle would have less, instead of more, than the original 11 grains of air in it—or, in other words, the pint of air would to that extent have become lighter.

But most people, when they speak of the wind and why it blows, think of the winds that blow in their own locality. In the British Isles, for instance, it is not so much the permanent and periodic winds that are of interest as the variable winds that are so constantly changing their direction and their force. These winds are best revealed by referring to the observations that are plotted on an ordinary weather chart. In the preparation of such charts the barometer readings taken at a large number of stations at an identical hour are shown, and lines called *isobars* are then drawn upon it to indicate the places that have the same atmospheric pressure. The wind observations are also plotted. Now an inspection of a large number of such charts at once reveals the fact that there is an intimate relation between the shape of these *isobaric lines* and the force and direction of the wind. A further

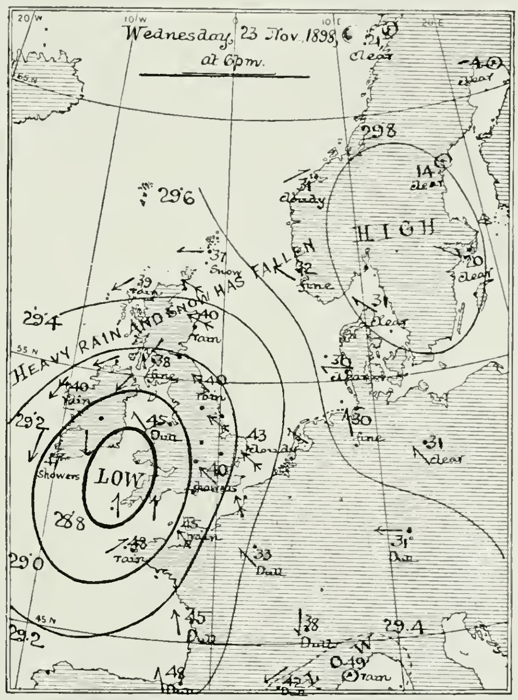


FIG. 8.—WEATHER CHART SHOWING CYCLONIC AND ANTICYCLONIC SYSTEMS.

The low-pressure (cyclonic) system is here lying over the British Isles.

inspection of the "isobars," or lines of equal atmospheric pressure, shows that there are areas where the barometer is high and others where it is low. Now the high areas are called *anticyclones*, and the low areas *cyclones*, and it is upon the position that these two systems occupy to one another that the force and direction of the wind depend (Figs. 8 and 9).

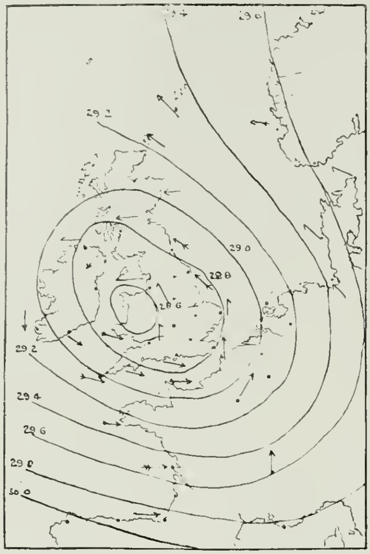


FIG. 9.—A CYCLONIC OR LOW-PRESSURE SYSTEM.

The figures refer to the height of the barometer in the various districts.

More especially does the wind derive its vigour from the "cyclones," or revolving storms, for it is indeed because of these atmospheric vortices that gales and violent winds so often hurry across the British Isles. The cyclones, moreover, are typical of another large class of winds—a class that is, perhaps, the most important of all. All the members of this family are rotatory—whirlwinds, tornadoes, waterspouts, and dust storms all belonging to it. Now as regards the cyclones it is well known that they travel round the earth along certain definite tracks, the storms that journey across the British Isles moving on a north-easterly course. Most storm tracks, moreover, owing to the rotation of the earth, are curved, and it is this shape that is by some authorities considered to impart the whirling motion to cyclonic storms, a motion that has so much to do with giving the wind its peculiar characteristics. The currents of air, for instance, as they move along this curved track travel at a different rate on the inside edge from what they do on the outside. This circumstance allows the centrifugal forces to come into play, the result being the rotatory motion exhibited by all storms, which, it may be remarked, resemble nothing so much as the eddies to be observed in any quickly running stream of water.

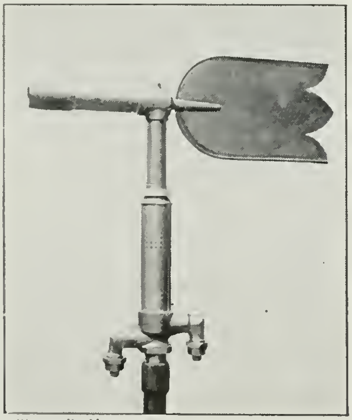


Photo: R. Munro.

FIG. 10.—TUBE HEAD OF DINES' ANEMOMETER.

In passing, it may be noted that in such eddies as whirlwinds, which are but a larger example of the eddies seen at street corners on a windy day, the

Photo: R. Munro.

FIG. 11.—RECORDING APPARATUS OF THE DINES' PRESSURE TUBE ANEMOMETER.

gyratory motion is due to the fact that the winds are rushing from many different quarters towards a common centre. As a rule, in such a whirl of winds there is a rising column of hot air that, rushing upwards very suddenly, causes the surrounding air to move inwards with great violence. Since, moreover, the winds do not all exactly hit the centre towards which they are moving, some of them are deflected, with the result that a revolving storm is produced. There are few parts of the earth's surface where such storms are not continually rising.

Returning to the consideration of the winds that are developed within the confines of a cyclonic storm, a weather chart reveals the fact that the deeper the atmospheric vortex the more violent are the winds. This may be illustrated by referring to the swirl of water that is produced when the plug is lifted from an ordinary wash basin, for in both cases there is a close relation between the depth of the eddy and the rate of movement. In a storm the lines of equal pressure lie very closely together, or, in other words, the atmospheric gradients are very steep, and are in great contrast with the lines in an anticyclone. The steeper, therefore, the gradients, the more violent will be the winds.*

But in addition to its rotatory motion a storm has also a forward movement, and it is to this that the varying direction of most winds are due. Moreover, these atmospheric eddies fill up or become shallow, and hence it is that the wind decreases in force. As regards the way in which the vigour of the wind is maintained, it seems probable that the moisture in the air is the great moving force. In most storms there is great condensation of moisture in the form of rain, hail, or snow, and, as previously mentioned, this means the liberation of latent heat that

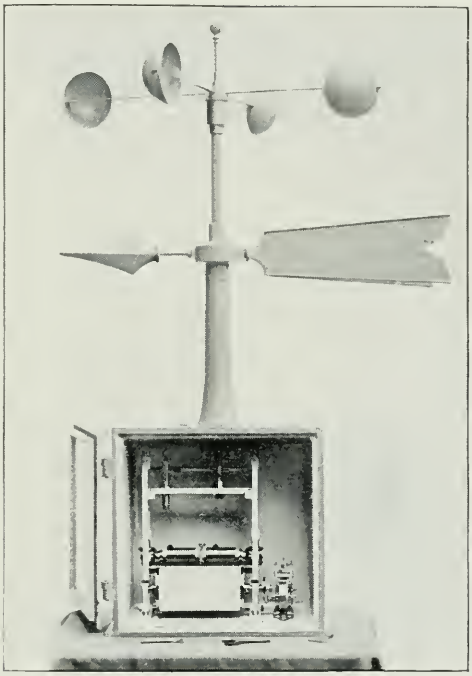


FIG. 12.—ROBINSON ANEMOMETER AT THE SCILLY ISLANDS.

* *See* "The Vagaries of British Weather," CASSELL'S POPULAR SCIENCE, Vol. II., p. 206.

serves as fuel to keep the storm in working order. Storms, indeed, like fires, move in the direction where fuel is most plentiful, and it seems likely that it is the presence or absence of moisture that regulates the direction in which many of the storms travel, modifying also their force or velocity.

It should now be a quite easy thing to understand why it is that the wind blows, and must blow, in the open spaces of the earth. In different parts of the world the sun shines with different degrees of heating power upon the ground and sea. Where it falls with most heating power it warms, expands, and makes lighter the air. Where it falls with least heating power the air remains unwarmed, unexpanded, and heavy, with its little particles squeezed more closely together. Both kinds of air, the heavy and the light are drawn towards the earth, because both have weight. But the heavy air is more forcibly and energetically drawn down than the light, and on that account gets nearer to the ground. But in doing so, as two different bodies cannot occupy the same portion of space at the same time, it drives the light air, which is less forcibly drawn, out of its way. Suppose that, in the annexed sketch (Fig. 13), A and B are two places on the earth which are 50 miles apart, and that at B each cubic foot of air weighs 1,700 grains, whilst at A, on account of stronger sunshine and greater warmth, each cubic foot weighs only 1,675 grains; then, as the air at B presses down with more strength than the air at A, and as both, with all the intermediate air along *c c* and *c e* are, in consequence of the disconnected state of their particles, free to stream and flow in whatever direction they are impelled, the light air at A will certainly give way before the stronger pressure of the heavy air at B, and the air from B will rush along the ground towards A. But rushing or moving air is *wind*. There will consequently be a wind blowing from B to A. The air always thus moves from the place where its weight or pressure is most towards the place where its weight or pressure is least. And in every case it moves with a velocity and strength which are greater in proportion as the difference of weight at the two places is greater, and which are less as that difference is less. Thus, if the wind were blowing from B to A, with a velocity of 30 miles an hour, when the air weighed 1,700 grains to the cubic foot at B and 1,675 grains at A—if suddenly the weight of the air at A were

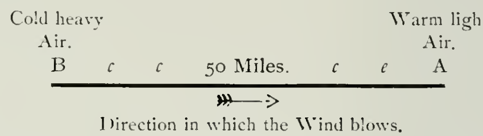


FIG. 13.—ILLUSTRATING PRESSURE OF HOT AND COLD AIR ON THE EARTH.

changed to 1,650 grains per cubic foot without any analogous change in the weight at B, the wind would then certainly blow from B to A with a velocity of 60, instead of 30, miles per hour.

It is now well understood that the wind is, in the main, at all times blowing from places where the air-pressure is great towards places where the air-pressure is small, and the way in which it does this, under the circumstance of continually altering pressures and of continually shifting situations of greatest and least pressure, has been reduced to a methodical explanation and expression, which is known as Buys Ballot's law, after the distinguished Dutch meteorologist who was the first to study the subject scientifically.

The direction and the force of the wind are recorded by means of *anemometers*, of which there are many different kinds. Some instruments record the velocity in miles per hour, while others, again, register its pressure on a square foot or some other chosen area. Commonly the

instrument records the direction as well as the force, although some observers are content to learn the direction of the wind by referring to an ordinary wind vane.

Of the "anemometers" that register the velocity of the wind the most familiar is probably the "cup anemometer," wherein the number of times the cups are blown round by the wind is registered on a dial or other recording apparatus. For recording the pressure of the wind a plate is sometimes kept facing the wind by means of a vane, the distance to which the plate is pushed backwards by the wind being a measure of its pressure.

In recent years the Dines' pressure tube anemometer (Figs. 10 and 11) has come largely into use, this instrument consisting of a tube the open mouth of which is kept facing the wind. The wind blows down this tube and moves a float, poised in water, the extent to which this float is displaced being a measure of the wind's pressure.

The Robinson anemometer, which measures both direction and velocity, is shown in Fig. 12.

FIG. 14.—KEW OBSERVATORY.

A FALLEN LEAF.

By ALEXANDER S. GALT.

BORN in the flush of green spring-time, all the summer long the leaf has fluttered joyously upon its parent bough. But the time of its decay is at hand. Within its tissues for weeks past a subtle change has been working, and now a sudden puff of wind has cast it down to the bosom of Mother Earth, discarded, fallen from its high estate. We watch it circling in the fitful puffs of the autumn wind. Only a leaf! Only something that the tree has done with and shed! Yet there are many stages to be traversed from the green to the withered leaf. The brilliant yellow of the elm, the ruddy brown of the sweet chestnut and the beech, and the innumerable shades of crimson and buff and yellow furnished by other plants, give to autumn a glory of its own that enable it to vie in charm with the glory of midsummer, and to surpass it in variety. And the fall of the leaf is the cause of it all. The gardener wots well of the beauties of the dying leaves, and with rare skill arranges them in copse and shrubbery so that they may display their varied hues to the best advantage; but he is apt to consider these selfsame leaves somewhat of a nuisance when they are strewn over lawn and garden path by each breath of the gentle autumn wind. He plies his broom busily amongst them then, careful only to get rid of them as speedily as may be. Perhaps he has no time to think of the complexity of these beautiful little organs, of the beauties of their structure, and the marvellously exact manner in which they fulfil the functions allotted to them.

FIG. 1.—GREEN LEAF OF THE BLACK POPLAR (*POPULUS NIGRA*).

A, *petiole*; *B*, *lamina or blade*.

FIG. 2.—FALLEN AND WITHERED.

We, however, may look into these matters, for there is many a lesson to be learned. First it will be well if we

consider their structure, since this will the better enable us to understand the threefold—or, rather, fourfold—function of the leaves.

We pick up a leaf at random; it belongs to a black poplar tree. A very

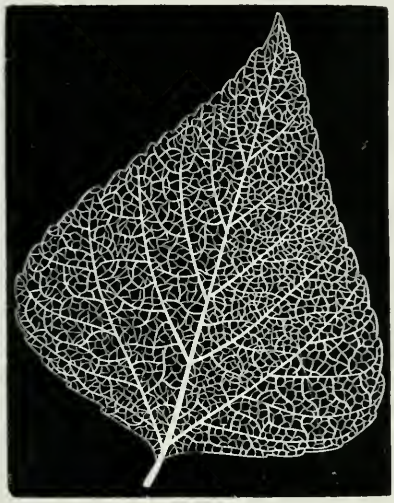


FIG. 3.—SKELETON OF THE BLACK POPLAR LEAF.

The softer parts—the intervenal tissue—have gone, leaving the bone-like nerves or veins.

casual examination with our unaided eyesight reveals that it is composed, broadly speaking, of two parts—stalk (or *petiole*) and blade (or *lamina*) (Fig. 1). If we look more closely at the end of the stalk which joined the leaf to the tree, we notice a little swelling at the base, and the wound appears to be covered over with a corky-like layer. If we were to climb the tree, and fit this leaf into the place from which it fell, we could not fail to notice the little scar that it has left behind. and if our eyes were keen and our observing faculties well trained we should likewise notice that this scar is also covered with a corky-like substance similar to that upon the base of the leaf stalk. I shall have occasion to refer again to this covering, but in the meantime it may be well to say that it has a great and important significance. Unless this *absciss layer*, as the botanist calls it, were formed, the fall of the leaf would be a long and tedious process. For the present we will descend our tree, none the worse for the gymnastic feat of climbing it, seeing that the said feat has been only performed in theory and not in fact.

Turning now to that part of the leaf which broadens out into the blade, we see how the leaf stalk has branched out repeatedly, until it forms a network of nerves or veins (Figs. 3, 8, 9, 10, and 11), the spaces between which are filled with softer tissue. This tissue, yellow now, was green but a month or two back. The cause of the green hue and the reason of the change to yellow we shall see later.

So far our eyes have been made to serve in the examination of the leaf. They have shown us something, but not nearly enough, and we must have recourse to artificial aids to eyesight in

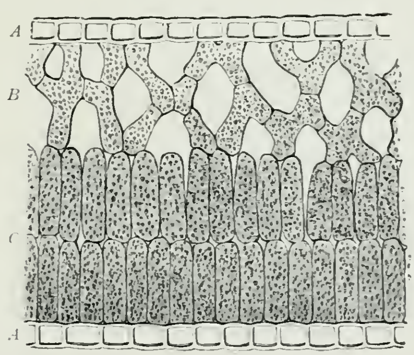


FIG. 4—TRANSVERSE SECTION THROUGH A LEAF, SHOWING STRUCTURE. A NUMBER OF DISTINCT "LAYERS" ARE MANIFEST.

A A, epidermis or skin—a protective layer. No pores or stomata are shown here.
B, loose tissue with large air spaces—"spongy parenchyma."
C, a wall of closely packed cells—"palisade parenchyma."

the form of a microscope. If a transverse section through the blade—that is, a cutting at right angles to the plane in which the blade is spread—be made and placed under the microscope, we

shall find that this soft green intervenal tissue is composed of several distinct layers of cells (Figs. 4 and 5). At both the top and bottom is a row of brick-shaped

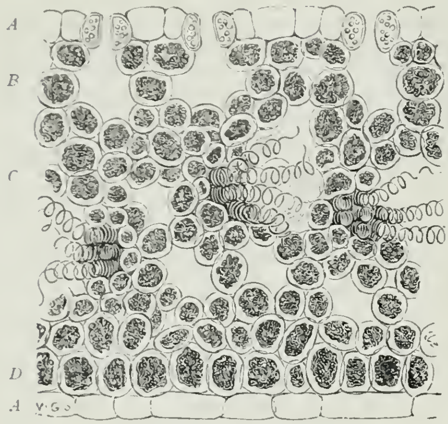


FIG. 5.—ANOTHER TRANSVERSE SECTION OF A LEAF, SHOWING EPIDERMIS, *A*, WITH PORES OR "STOMATA."

B, C, spongy tissue; D, palisade tissue

cells, for the most part empty or filled with air, with here and there openings, the *stomata*, or "breathing" and perspiration pores of the botanist. By means of a little careful manipulation, this *epidermis* or skin may be pulled off from the rest of the leaf and examined separately. It will then be found to be colourless, the green or yellow tint which it presents being due to the inner layers which it guards. It will be observed that the *stomata* (individually a *stoma*) are most numerous upon the underside of the leaf, comparatively few being seen on the upper side. They are bounded by two crescent-shaped cells (*guard cells*), which have the power of opening in the daylight and shutting in the dark. Reference to Figs. 6 and 7 will show these stomata with the guard cells and the opening between their contiguous faces. The number of these mouths varies, according to the plant, from a few dozen per square inch up to 160,000. Thus it has been calculated that the leaf of the lilac (*Syringa vulgaris*) has 708,750 of these openings, and the leaf of the lime (*Tilia vulgaris*) 1,053,000.

Next to the lower "epidermis" in the section will be seen a series of cells placed close together like bricks on end (the *palisade parenchyma*), while the middle portion of the leaf is occupied by tissue (*mesophyll*) composed of shorter and rounder cells, not so tightly packed, for we can plainly see the intercellular spaces, which are filled with air. The cells of all this inner tissue, as well as those of the "palisade parenchyma," are filled with *protoplasm*, which may be likened to the blood of animals; and in this protoplasm are to be seen floating numbers of very tiny green granules—the *chlorophyll* or *leaf green*. As the names suggest, it is the "leaf green" which gives the leaf its green hue, as, in fact, it does its yellow or brown one, or whatever tint may be assumed as the period of leaf-fall approaches. This change of the "chlorophyll" is not confined to leaves alone; it may be observed in ripening fruits, which change from a vivid green to rich red or yellow. The streaks and

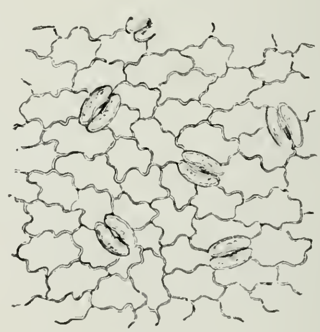


FIG. 6.—LEAF SKIN (*EPIDERMIS*), SHOWING PORES OR STOMATA.

Note the two "guard cells" and the "pore" between them.

tints of the rosy-cheeked apple, so dear to the juvenile mind, are due to this change of the chlorophyll. To the boy they mean that the erstwhile hard and green apple has become a toothsome

morsel that he makes haste to annex for his own benefit.

But this leaf-green has other and more important functions than merely to give the colour to the leaf, beautiful as this colour may be. It has to assist the plant to get its food—or, rather, that part of its food which is represented by the carbon—from the atmosphere. In conjunction with sunlight it has the power of breaking up the carbonic acid gas (CO_2) contained in the air, and of fixing the carbon—that is, retaining it—for the benefit of the plant; and included in this simple statement of its power lie results so far-reaching that we can only grip them by degrees.

We have now got a fair idea of the build of the leaf. There are many modifications of the shape and cutting of the blade, the length and character of the stalk, and the consistency of the tissue, but they do not concern us here. Volumes have been written upon this subject alone, and the systematic botanist is ever on the look-out for these differentiations, and makes use of them in identifying the numerous species of plants. All that we can do here is to obtain a broad, general idea of the main system upon which a leaf, no matter what its shape, is built. Now with regard to its functions. The botanist would sum these up in the following terms:—

(1) Respiration.

(2) Assimilation.

(3) Transpiration.

All healthy leaves carry on these three processes, and, in addition, our yellow leaf which we have been examining has also probably served to a greater or less degree as a dust-bin, in which the tree has deposited various excretory matters for which it had no further use, and which it desired to get rid of. It has, if I may use the term for an organism which is not popularly supposed to possess wisdom, very wisely seized the opportunity, when the leaf was preparing for its fall, of loading it with these cast-off materials. A marvellous provision this!

Referring now to these three main functions, it will be noticed that, while the leaf gets rid of the surplus water from the plant, it is also the lungs as well as the kitchen in which the raw food is cooked. Unfortunately the two processes of *respiration* and *assimilation* have been sadly mixed up in the lay mind, and this confusion is without doubt

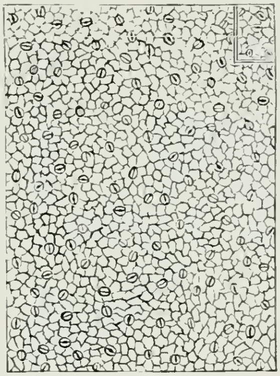


FIG. 7.—MANY HUNDREDS OF STOMATA, OR PORES, LIE IN EACH SQUARE INCH OF SURFACE.

largely due to the very loose fashion in which they have been described in popular and other books. Many people fail to grip the idea that a plant must breathe. Fewer still understand that it breathes the same gases as an animal, that it takes in oxygen and gets rid of carbonic acid gas as the product of combustion. Not infrequently the idea is held that the animal takes in oxygen and breathes out carbonic acid gas, and that the plant takes in carbonic acid gas and gives off oxygen, being in this way the natural purifier of the atmosphere for animal life. So it is; but this is only half the truth. The balance of Nature is far more subtly constructed than this, and not to be so speedily summed up.

adjudicated upon, and dismissed. Let us see exactly how we stand.

Respiration, or breathing, is the process by which the plant obtains its oxygen from the atmosphere. Oxygen it must have to give it energy to carry on its work, to elaborate the various crude materials drawn up by the roots, and to carry on the work of the plant generally. Respiration is therefore a *destructive* process, and the product of this destruction is carbonic acid gas. It goes on without ceasing, by day as well as by night, and when it ceases the plant dies. All parts of a plant breathe, although certainly respiration is reduced to a very low ebb in the comparatively dry seed.

Assimilation, on the other hand, is a *constructive* process, for by it the plant obtains its carbon from the atmosphere through the carbon dioxide which it contains. Now this gas enters into the composition of ordinary air in the proportion of about four parts to 10,000 of air by volume; over towns and in badly ventilated rooms the proportion may be many times greater than this. It has been estimated that our atmosphere contains 138,616,075,892 tons of carbon. Under this process CO_2 is decomposed into its two constituents, carbon and oxygen, the carbon being retained and the oxygen rejected. Some of this oxygen is given off—possibly all of it: but this part of assimilation is not well understood. A detailed description of the probable process would be rather out of place in these pages. Now as assimilation can only take place in the green parts of plants during sunlight,* it ceases as soon as the daylight disappears.

Transpiration may be defined as plant perspiration; it is the way in which the organism gets rid of its surplus water. The subject of the nutrition of plants has been dealt with in some detail in another paper,† and it was then seen how important a part in the economy of the plant water plays. Just now we are chiefly concerned with getting rid of the water, and we see how those curious little mouths, the stomata, of the leaves help. Under the influence of sunlight they open; and through these open mouths the evaporating water passes. Now this perspiration may not be always noticeable. Neither is the perspiration from our own skin, if it is healthy, always appreciable; but, like the sweat from the leaf, it is still there. That water is actually got rid of in this

FIG. 8.—SKELETON LEAVES.

* Some artificial lights, notably the electric, permit assimilation in some degree, but plants subjected to these influences are always unhealthy, and present an unnatural appearance. We should expect this, seeing that they are robbed of their sleep time, which is as necessary to them as it is to us.

† CASSELL'S POPULAR SCIENCE, Vol. I., p. 280.

fashion may be shown by the following simple experiment. Take a small pot plant —no matter what the kind—cover the soil in the pot with a collar of fairly stiff paper, letting this collar rest upon the pot rim, and cover the whole with a bell-glass. Stand the bell-glass and its occupant in the full sunlight in a window, and watch results. Before long a misty film will be gradually observed creeping over the inner surface of the glass shade, and this, upon examination, proves to be water, and the glass finally presents the same appearance as is obtained by breathing upon a window-pane. Now, where has this water come from? It cannot have come from moisture

FIG. 10.—SKELETON LEAF OF SYCAMORE.

FIG. 9.—SKELETON LEAF OF THE PALMATE MAPLE.

evaporated from the soil in the pot, for the paper collar has prevented that. It is simply the condensed watery vapour perspired by the plant through its leaves.

FIG. 11.—SKELETON LEAF OF ANOTHER MAPLE.

Not content with expelling water through the stomata by day, some plants have comparatively large water-pores, usually opening from a termination of one of the veins, and they get rid of the water very expeditiously through these. These water-pores are in active work through the hours of darkness (the stomata, it will be observed, are not), and, when the morning comes, large drops of water may be seen hanging from the points of the leaves. When the plants are growing outdoors these drops are commonly but erroneously spoken of as dew. Here, again, we have an instance of the necessity of carefully balancing all the facts before we jump to conclusions about anything. A dew-drop is a far smaller thing than is generally supposed.* Members of the great

* *See* "Dew and Hoar Frost," CASSELL'S POPULAR SCIENCE, Vol. II., p. 112.

natural order *Aroideæ*, to which our common Cuckoo Pint (*Arum maculatum*)

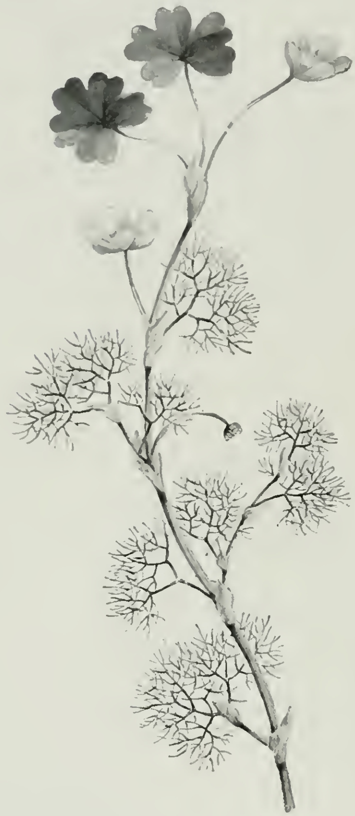


FIG. 12.—ONE OF THE WATER BUTTERCUPS (*RANUNCULUS AQUATILIS LENORMANDI*).

The submerged leaves A are very finely cut, so that they offer little resistance to the current of the stream. The aërial leaves, B, are of quite a different shape.

belongs, are noticeable for these water-pores. In some of those pretty little Alpine Saxifrages, now so much in favour with lovers of rock gardens, the water-pores can be seen quite plainly, even with the naked eye, for the little depressions or pits in which they are situated are conspicuous by the deposit of carbonate of lime which has been left behind.

Physiological botanists have made many interesting calculations as to the quantity of water transpired by certain plants. Naturally this varies considerably, according to the kind of plant. Thus a sunflower only $3\frac{1}{2}$ feet in height (and there are many finer specimens than this in "Suburbia") will get rid of from 20 to 30 oz. (avoirdupois) every twenty-four hours. An acre of cabbages, planted eighteen inches apart each way, will pass into the air the almost incredible quantity of nearly $10\frac{1}{2}$ tons of water every twenty-four hours.

The question that comes naturally to the lips is, Where does the water all go to? And the only answer is that it passes into the air we breathe, and tends to make it moister and more kindly for that lord of creation, Man, and the beasts whose lot it is to serve him. The presence of vegetation has, indeed, a marvellous effect upon the climate of a country—far more, in fact, than is popularly supposed. The subject, however, is much too vast to be detailed now.

FIG. 13.—THE WATER VIOLET (*HOTTONIA PALUSTRIS*).

This pretty aquatic frequently fills the water of shallow ponds and ditches with an intricate network of leaves.

But at least those of us who are inclined to regard that frail leaf which we held in our hands but a few moments ago as a very insignificant thing indeed are

brought up with a round turn. Who will now say, "*Only* a leaf," when it is the leaf that has so great a say in the making of the climatic conditions under which we live ?

But enough has been said about transpiration. Reverting for a moment to the subject of respiration, the question, How do plants growing in water obtain their oxygen ? will naturally be asked. The answer is that enough oxygen is present in the water to keep them going, and we always find that the leaves of plants which are submerged are very finely split up so as to present as much surface as possible to obtain this oxygen. This is well seen in the various forms of the Water Buttercup (*Ranunculus aquatilis*) (Fig. 12), where we notice in addition that the floating leaves are not much divided—in fact, almost entire—while those which have to live beneath the surface of the water are quite feathery in appearance. The leaves of the water violet (*Hottonia palustris*). a pretty occupant of shallow ponds and ditches (Fig. 13), are also very finely cut, and quite lace-like in pattern. It is very probable that the cutting up of the submerged leaves is largely due to an effort on the part of the plant to expose as large a chlorophyll-bearing surface as possible to the action of the dim light that prevails in these subaqueous regions. It is quite certain also that finely divided leaves offer less resistance to a current of water than entire ones. From this point of view we should expect to find submerged leaves generally built upon this or a similar pattern, and our expectations would not be disappointed.

Now we come to the actual fall of the leaf, and we are inclined to ask ourselves why, if the leaf is such an important organ, the trees and shrubs can spare it. At first it seems to be a great waste of energy to part with the leaves in the autumn and have to produce new ones in the spring, as is the custom of our friend the poplar. The rigour of our winters is in a great measure accountable for this. The thin tissue of the leaf is tender and easily injured by frost, and the tree

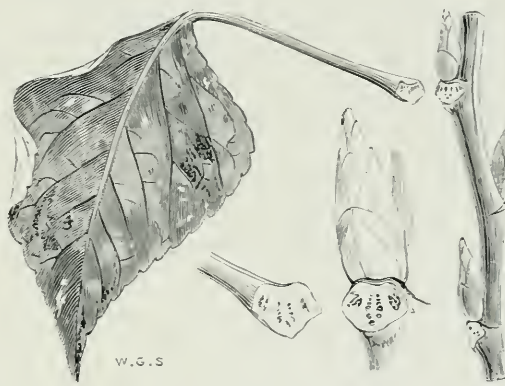


FIG. 14. — LEAF OF LILAC SHOWING SCAR WHERE THE ABSCISS LAYER HAS RUPTURED.

has learned—or, rather, its ancestors have learned—by long years of experience to present only the tougher portions of their anatomy. and those clothed with a thicker skin than the leaf possesses, to the embraces of stern Boreas. During this period of sleep the vital processes are at a comparatively low ebb, so low, in fact, that the tree can do without the leaves. But it works them hard during the season of growth, and it is probable that in sacrificing them in the autumn. after they have elaborated sufficient store of food, and thus provided for a succession of leaves, the sacrifice is more apparent than real, and greater efficiency of lung and kitchen power is obtained thereby. Even in the case of those trees which are evergreen, it will be noticed that while the *tree* is evergreen the *leaf* is not. The leaf lasts more than one season ; it may, indeed, flourish for two or three years, but it is ultimately shed as its less long-lived relative upon the poplar. There is this difference, however, that

in the deciduous tree the young leaves do not emerge from the bud until long after the old ones have fallen; in the evergreens the new leaves come before the old ones go—in fact, the new ones frequently push the old ones off to make room for themselves, and this without the slightest compunction. Leaf nature, like other phases of our great mistress, has no ruth and little scruple. There must be no drones in her hive.

Thus far we have confined ourselves to showing *why* the leaf falls. Now we may turn our attention to the consideration of *how* it falls. And in doing this our attention will first be arrested by that corky-like skin which clothes the scar and the base of the leaf-stalk (Fig. 14), this all-important "absciss layer."

Towards the close of summer, in all deciduous trees—when the period of usefulness is drawing to a close in the case of evergreens—a transverse layer of corky tissue begins to make its appearance at the junction of the leaf with the branch. Commencing next the epidermis, it passes inwards, gradually shutting off vital connection between leaf and branch. Finally, the dissepiment invades the fibro-vascular bundles, the articulation is complete, and no crude sap can pass from branch to leaf, neither can the elaborated sap be returned. There the leaf is waiting, of the tree and yet not of it, waiting merely for the gentle sideway puff of wind that shall cause the absciss layer to break across, and send the yellowed leaf fluttering to join its companions upon the sward below. Meanwhile, those changes in the chlorophyll before referred to have taken place, and the tissue of the blade has been loaded with the various excretory matters which have to be got rid of somehow. As the absciss layer ruptures through the middle it leaves a cap of the corky tissue to clothe the scar upon the branch and prevent loss of sap. This, again, although a simple, is a wise provision, for although the loss through one open wound would be insignificant, hundreds of thousands of wounds would be serious for the tree. Until the absciss layer is formed, therefore, the leaf requires considerable force to detach it; when it is formed, only a little pressure is needed.

Frequently it will be noticed that young oaks and hornbeams retain their dead and withered leaves all through the winter, as if in defiance of the general rule governing their brethren. In these cases the absciss layer is either incomplete or not developed at all. Again, if a branch in full leafage be broken off from the parent tree in the height of summer, the leaves, although dead, will cling to it for long. This devotion is also due to the non-formation of the absciss layer.

WEIGHING THE EARTH.

By WILLIAM ACKROYD, F.I.C.

IN 1878, while the busy merchants of Manchester were keenly bartering on their Rialto, some their cotton, and some their corn, goods arrived and goods to come, the contents of richly laden ships still on the ocean—they, their goods, and the mighty earth itself, with all that is thereon and therein, were being weighed not very far away. The mysterious operation, making puny and insignificant the weighings effected for the merchant princes of Cottonopolis, was being performed in a cellar under the Owen's College. This, however, was only one of the most recent of many such weighings not a whit less extraordinary, for during the last two hundred years the earth has often been weighed, after very different methods, and the results obtained—considering the magnitude of the task, and the ways and means adopted—have been sufficiently near to each other to merit our confidence.

One has a difficulty in realising the immensity of the mass that has been on these occasions, figuratively speaking, put into the scales. In our endeavour to grasp some idea of it, let us follow in imagination those emigrants now leaving Gravesend and bound for the Australian continent. The good ship, freighted with its human cargo, calls at Plymouth, and ere long is passing down the Atlantic Ocean; it ploughs its way through the deep with an average speed of over two hundred miles a day, but if we trace its progress on the map we see that it moves comparatively slowly. Twenty-five days after starting, the travellers have reached the Cape, and in thirty days more they have arrived at Melbourne. Day after day they have proceeded at what has seemed to them a quick pace, leaving behind the white cliffs of Albion—perhaps made whiter by a mantle of snow—for the scorching heat of the tropics, finally reaching, after an excursion of some twelve thousand miles, their new home at the Antipodes. And now to get round the earth we must proceed farther than the emigrants. We accordingly pass down the Bass Strait and enter the vast stretch of the Pacific Ocean; then, after very many days, during which we have been again and again delighted with glimpses of the Polynesian islands—oases in a desert of waters—we arrive at the Canal in the Isthmus of Panama, which we will take the liberty of fancying has been successfully cut through; and now a comparatively short journey across the North Atlantic brings us home again, after about eighteen weeks' continuous steaming. We have circumnavigated the earth, gone round the vast ball on which we live; and now, with a lively conception of its magnitude, let us consider how it has been weighed.

Some idea of how we ought to proceed will be gained if we ponder how it would be possible to weigh without scales one of those big stone balls which top the gate-posts in front of a Cromwellian mansion. A minute inspection of the ball shows us that it is of the same kind of stone as that to be found in a neighbouring quarry. It is easy to ascertain the weight of a cubic inch of this quality of stone, and afterwards to measure the number of cubic inches which the ball contains. A simple multiplication sum will then give us the weight of the large stone ball. We have similarly to ascertain, in the case of the earth, (1)

the number of cubic miles in it, and (2) the weight of a cubic mile of it.

It is a curious fact that the distance round the earth was measured some two thousand years ago by the philosopher Eratosthenes. He regarded the earth as an immovable globe, and he attempted to measure its magnitude in the same way

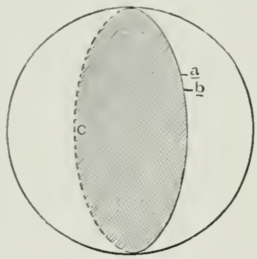


FIG. I.—ILLUSTRATING HOW THE CIRCUMFERENCE OF THE EARTH WAS MEASURED.

as we do to-day. Imagining the circumference of a great circle *a b c* (Fig. 1) to extend all round the earth and pass through Alexandria, *a*, and Syene, the modern Assouan, *b*, he attempted to find out what number of degrees of this circumference was intercepted between the two places—in other words, what was their difference of latitude. His results taught him that the arc of earth's surface extending from Alexandria to Syene —*i.e. a b*, was about the fiftieth part of the whole circumference ; and taking the distance between them and multiplying by fifty, he roughly ascertained the whole distance round the earth, from which one may readily calculate the diameter, and then the solid contents. These are the days of exact experiment, and what Eratosthenes did roughly we do with much greater accuracy. Now the length of the line *a b* would be ascertained by very exact trigonometrical methods, so exact that there would probably be an error of two or three inches only in measuring the four to five hundred miles. As the result of calculations, based on accurate measurements of this kind, we learn that, considering the earth to be a sphere, it has a diameter of 7,912·41 miles, and solid contents of 259,373 millions of cubic miles.

We have next to ascertain the weight of a cubic mile of the earth—a matter of the greatest difficulty, seeing that the rocks which compose it are of every degree of density. The surface rocks vary in their specific gravity, most of them being two and a half to three times heavier than an equal bulk of water ; and there can be no doubt that the rocks of the interior will become heavier and heavier as we proceed towards the centre, on account of the great pressure of superincumbent strata. It will be apparent, therefore, that the weight of a cubic mile of the earth's substance will vary at the surface with the quality of it ; and, further, that a cubic mile of material, say at a depth of twenty miles, will weigh much more than a cubic mile of similar material at the earth's surface. We require, then, to know some way of ascertaining the *average* weight of a cubic mile of the earth's substance, or, to put the problem in a more convenient form still, we have to ascertain how many times heavier the earth is than a sphere of water of the same magnitude, and of uniform density throughout. There have been some four methods devised for this purpose, and I will enter into such details concerning them as my readers will readily understand.

A schoolboy is often puzzled to account for the fact that people on the other side of the earth, with their feet pointing towards ours, do not fall off, and he never fully understands how this cannot happen until he realises that the earth pulls everything towards it, wherever it may be. In virtue of the earth's pull a weight falls downwards from a height with an ever-increasing speed, and a pendulum swings to and fro until its excursions

have become so shortened by friction and the resistance of the atmosphere that it stops. We usually speak of the *force* with which the earth pulls a thing towards it as the *weight* of that thing,* and when, in the common operation of weighing goods, we place them in one pan of a pair of scales and in the other place certain standards (which we speak of as hundredweights or pounds), until the earth's pull on the goods is just balanced by the earth's pull on the standard weights, then we say they have both the same weight, and we measure the weight of the goods by the standards we have employed. Suppose, now, we were to employ for weighing, instead of the usual pair of scales, a spring balance in which we measure the weight of a thing by the amount it will stretch out a spring, and not by counterpoising it with known standards, we should find a substance with such an instrument to be inconstant in its weight: it would weigh less at the top of a mountain than it would down at the bottom of a valley. It is very evident that the quantity of matter in the substance would remain unaltered during its transit from the top to the bottom of the mountain, although its weight increased. The quantity of matter in a body is spoken of as its *mass*, a very short and convenient word. It will now be perceived that a change of position alone will not alter the *mass* of an article, although it may very materially alter its *weight* or the force with which it is pulled towards a planet. Here is a fanciful example to the point. There goes a "jolly fellow," who weighs sixteen stones, if he weighs a pound; in other words, the earth pulls at him with a force which would register sixteen stones if he were put into the pan of a very large spring balance. Suppose him now, if it were possible, instantly transported to the surface let us say of Jupiter. His *mass* would be unaltered, but upon sitting once more in the pan of the spring balance he would *weigh* 39 stones and 9 lb.!

This pull, or attraction, is something universal. The sun pulls at all the planets around it, the planets pull at the sun and at each other, and every particle of matter in the universe pulls at every other particle with a force whose direction is that of the line joining the two, and whose magnitude is proportional to the product of their masses divided by the square of their distance from each other. In the case we have just given, the reader will readily see now how the result was obtained. Each planet pulls at a thing on its surface as if its own mass were concentrated to a point at its centre. From the centre of Jupiter to its surface is eleven times longer than from the centre of the earth to its surface, hence the attraction on the man at the surface of Jupiter would be $\frac{1}{11^2} = \frac{1}{121}$th of the pull on him at the surface of the earth. But the mass of Jupiter is, in round numbers, 300 times more than the earth's, therefore, so far as mass is concerned, its pull would be 300 times greater, or $\frac{300}{121}$ths. Now the pull on the man on the earth being sixteen stones, on Jupiter it will be $\frac{300}{121}$ths of sixteen stones—*i.e.* about 39 stones 9 lb.

It will now be fully understood that the earth's pull on things at or near its surface may be modified by various circumstances of position. We shall here consider three cases:—

(1) How a plumb line may be pulled out of the perpendicular.

(2) How the weight of a pound of lead may be increased.

(3) How the number of swings of a pendulum of constant length may be altered.

(1) If a weight, *m* (Fig. 2), be attached to a string and suspended from a fixed point, *s*, the string points towards the

* See "How and Why a Stone Falls," CASSELL'S POPULAR SCIENCE, Vol. I., p. 183.

centre of the earth. The great mass of the earth, E, pulls at the small mass, *m*, in that direction, but a mountain, M, close

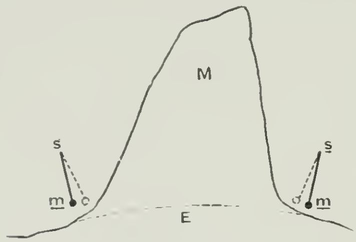


FIG. 2.—A MOUNTAIN PULLS A PARTICLE TOWARDS IT.

M, a mountain; m a piece of lead: the dotted lines show the "pull" of M.

by will exert its attraction on the weight *m*, and draw it a little towards it, so that the plumb line no longer points to the earth's centre. Ordinary methods of observation here altogether fail us, and it is only by sidereal observations made with extreme care that the effect has been noted and measured. Chimborazo caused a deviation of 11″, according to Bouguer and La Condamine; the sum of the deviations caused by Schiehallion in Scotland (Fig. 8) on opposite sides of the

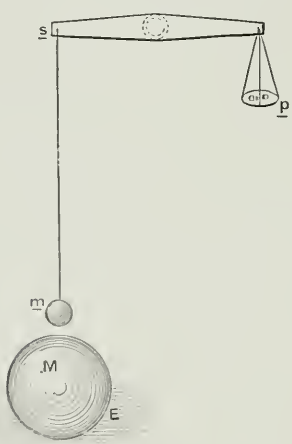


FIG. 3.—"PULL" OF A HEAVY METAL SPHERE (M) AS SHOWN BY A DELICATE CHEMICAL BALANCE.

mountain was 11·6″ in the observations of Maskelyne; and Sir Henry James obtained a joint deflection of 4·21″ caused by Arthur's Seat (Fig. 5) near Edinburgh.

(2) When a weight, *m* (Fig. 3), is attached to one end of a chemical balance of extraordinary sensitiveness (*s*), we can counterbalance the earth's pull on it with great exactness by means of weights in the pan, *p*, and riders on the beam. If now we bring a heavy mass of metal, M, directly under *m*, the pull of M is added to the earth's, E—in other words, the weight of *m* is increased. Professor J. H. Poynting made the experiment, and with a weight, *m*, of nearly 1 lb. (452·92 grammes), and a large lead mass, M, of 340 lb. (154 220·6 grms.) the weight of *m*

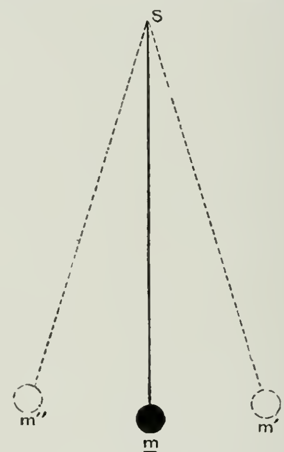


FIG. 4.—THE SWING OF A PENDULUM.

was increased by $\frac{1}{45,000,000}$th. The series of experiments were made with great care in Owen's College, Manchester.

(3) A pendulum consists of a bob, *m*, suspended from a point, *s* (Fig. 4). By lifting the bob to *m′* and letting go, the earth pulls it downwards, and in virtue of this pull it swings down to *m* and continues its progress to *m″*; it then proceeds over the same course backwards, and repeats the to-and-fro motion until it is stopped by the resistance of the air and friction at the point *s*. If the pull on *m* is decreased, the speed of the pendulum will be slackened, and this in a way which will give us a measure of the exact amount of decrease of the pull. A pendulum that makes 86,535 vibrations

FIG. 5.—ARTHUR'S SEAT, FROM ST. LEONARD'S.

in a mean solar day in London will make only 86,400 at the equator in the same time, because the pull in the latter position is less than at the former, and a simple calculation with these figures shows us exactly how much less. What would be the effect if we took the pendulum down a pit? Newton has shown that any particle of matter, *b* (Fig. 6), within a sphere is equally attracted in every direction by all portions of the external hollow shell, M M, just inside which it rests, and the pull of this shell on the particle may therefore be neglected. Let *a b* represent the shaft of a pit; a pendulum vibrating at its mouth, *a*, will make a certain number of vibrations in a given time, the result of the whole earth's pull upon its bob; but at the bottom of the shaft the bob of a perfectly similar pendulum will be pulled by only the internal sphere, E; and if the earth were homogeneous throughout, the number of vibrations would be reduced in this position. The earth, however, is not of uniform density, and such are the conditions that the internal sphere, E, which attracts the pendulum at *b*, does so with more force than the whole earth attracts *a*. There is thus an increase in the number of vibrations at the bottom of the pit. The late Sir G. B. Airy, Astronomer Royal, made several attempts to get accurate quantitative results, and, unlike the ordinary run of calm astronomical observations, his experiments were not unattended with danger. The first two attempts were made at the Dolcoath mine in Cornwall, but both failed: the first on account of his instruments being destroyed in the shaft, and the second because of the subsidence of a huge mass of rock, which brought the experiments to a sudden and premature conclusion. Nearly thirty years after, in 1854, a third attempt was made at the Harton Colliery, near South Shields, 1,200 feet deep, and it was completely successful. It was found that a pendulum beating seconds at the mouth of the pit gained $2\frac{1}{4}$ seconds per day on a similar one at the bottom.

Each of these series of observations furnished data for ascertaining the mean density of the earth—*i.e.* for telling exactly how much heavier the earth is than a ball of water of uniform density and of equal magnitude. In every instance the influence of a known mass, M, on a lesser mass, *m* (*see* Figs. 2, 3, and 5), is compared with the earth's influence or pull on it, and then by many and various calculations the earth's density is arrived at. It will give some idea of the labour expended in getting the value of M when we mention that Schiehallion (Fig. 8) had to be accurately modelled and surveyed, and that the densities of its various mineral constituents had to be ascertained, while in the case of the Harton Colliery experiments, the surrounding country had to be extensively surveyed, the strata had to be studied, and their specific gravities taken.

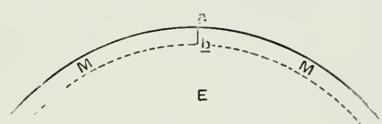


FIG. 6.—ILLUSTRATING THE PULL OF THE EARTH ON A PARTICLE WITHIN IT.

E, the earth; M M, external shell of earth; a b, shaft of a pit.

Towards the end of the eighteenth century, some remarkable weighings of the earth were made by one whose name is well known in the annals of English science: for, although the Hon. Henry Cavendish was perhaps the most eccentric man of his time, he was one of the busiest in the search after truth. From his habits unfettered by social or political engagements, and from the accident of birth exceedingly wealthy, he was able to devote most of his time to research, not in one, but many branches of science, so that Biot has well said of him that he

was "the richest of all the wise men, and probably also the wisest of all the rich."* He numbered among his warmest friends the Rev. John Michell, who devised the torsion balance for weighing the earth. Michell died before he could make the experiments, and the apparatus came into Cavendish's hands, who, after improving it, made the requisite measurements, and communicated his results to the Royal Society in 1798, in a paper entitled, "Experiments to Determine the Density of the Earth."

The torsion balance is of exceedingly simple construction, consisting of a horizontal rod, *r* (Fig. 7), suspended by a fine wire from a fixed support, *s*. When the rod is turned round in a horizontal plane the wire is twisted, and, being elastic, tends to untwist itself. The strength of the pull which turns the rod is proportionate to the angle through which it is turned —*i.e.* if a certain pull will turn the rod through an angle of 3°, a pull of double the strength will turn it through 6°. If, then, two small metal spheres, *m m*, be attached to the ends of the rod, *r*, it appears not improbable that if larger spheres, M M, be brought near them, as in Fig. 7, some indication may be obtained of the pull which they exert on the lesser balls in virtue of that universal attraction we have already mentioned. When every precaution has been taken to shield the balls from air currents and other sources of error, it is found that the spheres, M M, have a measurable influence on the swing of the balls, *m m*, when vibrating, from which it is possible to determine what portion of the weight (*i.e.* pull of the earth) of either ball, *m*, is equal to the pull which M exerts upon it. The mass of M is known, and from the other data obtained the density of the earth may be calculated.

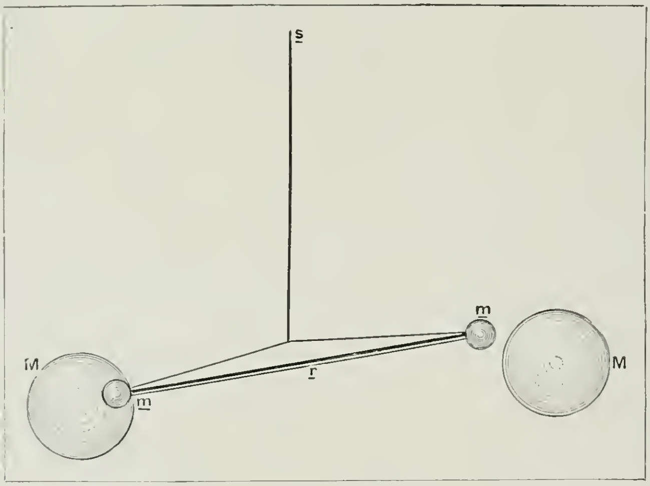


FIG. 7.—THE TORSION BALANCE.

A horizontal rod, r, is suspended from s. At each end of r is a small metal sphere, m. M M are two large metal spheres whose attraction to the little ones is to be tested.

When the results of these various experiments have been calculated out, figures have been obtained for the mean density of the earth which have not been far from an average of $5\frac{1}{2}$, while the best among them have very closely approached this result. Thus, Mr. C. V. Boys made a determination in 1894 with an improved torsion balance with filament of quartz,

* "Le plus riche de tous les savans, et probablement aussi, le plus savant de tous les riches."

and the density obtained was 5·527. In 1897 a nearly identical result was got by Braun, who employed the torsion method; and in 1898 Richarz and Krigar-Menzel, by balance determinations, got the result 5·505. We have by no means exhausted the list of experimenters—which includes the names of Plana and Carlini, Reich, Baily, von Jolly, Berget, Wilsing and Cornu, and Baille—but it is not necessary to enter into further details, as they but multiply the already ample proofs that the earth's mean density is very nearly $5\frac{1}{2}$ times that of a similarly sized globe of water, and from which we may calculate, with Sir John Herschell, that its weight is over five thousand trillions of tons, or, more exactly, 5,852,000,000,000,000,000,000 tons.

Photo: G. W. Wilson & Co., Aberdeen.

FIG. 8.—KINLOCH RANNOCH AND SCHIEHALLION

TASTE.

In order to understand the phenomena which are associated with the sense of taste, we must first direct our attention to the functions of the organs that are concerned as exhibited in ourselves, for these are the most interesting to all of us.

The chief, though not the sole, region with which are connected the special end-organs of the sense of taste is that muscular member, the tongue, which is of such great assistance to us in masticating our food and in giving utterance to our thoughts. On the surface of this tongue there are to be distinguished a number of more or less minute projections, which are known generally as *papillæ*. Of these some are comparatively large (Fig. 1, *cv*), and are surrounded by a wall of the soft mucous layer which invests the muscular body of the tongue: it is in consequence of this arrangement that they are called *circumvallate papillæ*. Others, which are smaller, and form a rounded cap at the upper extremity of their narrower stalks (whence they are called *fungiform*), are more numerous than the circumvallate papillæ, of which there are not more than twelve (rarely so many) on the human tongue. There still remains a third set of yet smaller processes, which are so delicate as to have received the name of thread-like or *filiform* papillæ.

The papillæ consist essentially of a layer of flattened "epithelial" cells investing a mass of "connective" tissue, and containing in their midst a number of bulb-like bodies, which appear to be the proper end-organs of the nerves of taste (or gustatory nerves); these bulb-like or flask-shaped bodies open on the surface of this "epithelium" by a circular taste-pore, which forms, as it were, the orifice of the neck of the flask (Fig. 2). If we compare what obtains in a number of animals, we find that the taste-bulbs vary considerably in their more intimate characters; but it is not necessary for us to enter into the details of the arrangement of their several parts. It is sufficient to know that they are chiefly found around the sides of the circumvallate papillæ, though they are also to be found upon the fungiform processes. In their essential characters they are thus con-

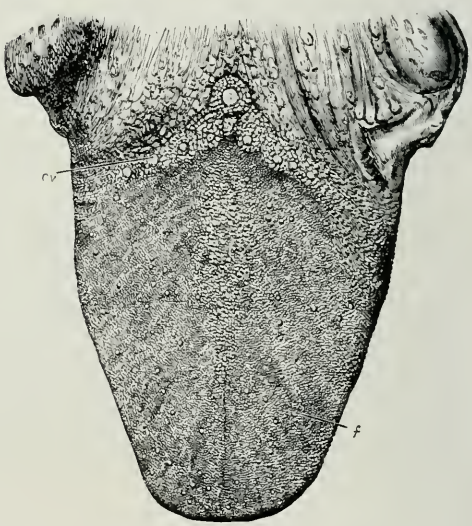


FIG. 1.—THE HUMAN TONGUE.

cv, circumvallate; f, fungiform, papillæ.
It is these papillæ which contain the flask-like bodies shown in Fig. 2, which contain the sensitive ends of the taste nerves.

stituted; they are made up of two different kinds of cells—of these the outer or covering cells are elongated bodies filled with a clear protoplasm, which are not connected with nerve branches; they are of pretty much the same breadth throughout, exhibiting only considerable diminution of size at those points at which they approach the neighbourhood

of the above-mentioned taste-pore; the inner cells, which are technically known as *gustatory*, are long and thin,

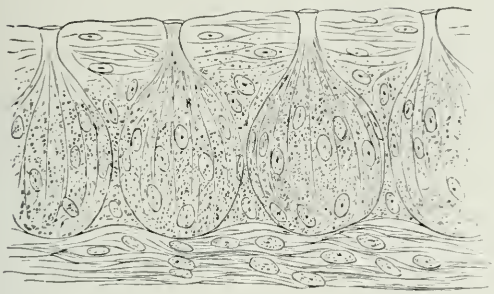


FIG. 2.—TASTE-BULBS OF THE RABBIT.
(After Engelmann.)

and have a broader outer and a much more delicate inner process (Fig. 4). On the circumvallate papillæ, they are to be found only in those portions which are guarded by the fold of mucous membrane which forms, as it were, a rampart around them; on the fungiform papillæ they are more sparsely distributed, and from these the filiform papillæ are to be distinguished by the presence of a number of more or less stiff hairs, which, taking the place of the covering of specially modified epithelium found on the other papillæ, seem to afford to them the power of assisting in the mastication of the food, just as much as (if not, indeed, much more than) in detecting the sensations of taste which the food, taken into the mouth, excites.

Let us turn now to the second agents

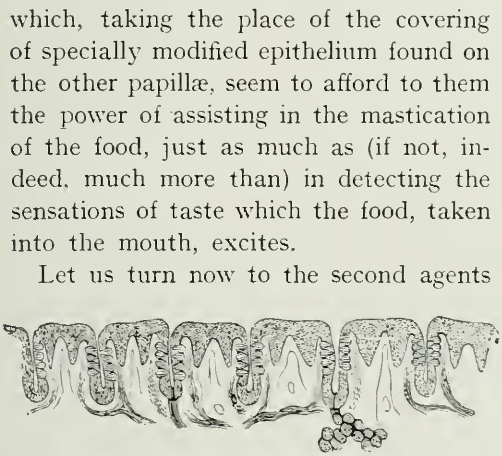


FIG. 3.—TRANSVERSE SECTION THROUGH TASTE-FOLDS OF THE RABBIT.
(After Engelmann.)

in sensation—to the nerve-branches, which are especially connected with the taste-bulbs. These we will discuss before we pass on to consider the somewhat more difficult question as to the special nerves by which these branches are connected with the brain, or, in other words, with that reasoning organ which aids us in forming our judgment, and keeps a register of the sensations experienced in the past. Fine nerve branches, aided by rounded, cell-like "ganglia," pass off from the larger nerve-trunks into each papilla; breaking up, and forming a meshwork, or *plexus*, beneath it, the connecting strands of nerve fibre then pass on into it, and make their way towards the surface. Careful as the observations have been on the part of those who have examined into this subject, with the most elaborate assistance

FIG. 4.—TASTE-CELLS.
a, separate cells; b, a taste-cell with covering cells.

that modern methods of microscopic research afford, they have not yet been able to make out in all their details the relations which subsist between the more delicate nerve-fibrils and the gustatory cells.

From that great mass of nervous and other tissue which in man constitutes the brain, there are ordinarily said to be given off, on each side, twelve distinct nerves. Some of these nerves are specially set apart for the purpose of acting on the muscles of the face, or on the muscles that move the eye-ball; others give to the brain indication of what is affecting the skin of the face, and others send some fibres to organs as far away from the brain as the heart, the lungs, and the stomach. Now, all those great nerves

which arise from the spinal cord give off two branches, one of which has the duty of conveying to the spinal cord, and so to the brain, the results of affections of the end-organs—and these are *sensory* nerves; others have for their function to convey what may well be called messages from the brain to the different muscles of the body—and these are the *motor* nerves.* When we examine those branches which are given off directly from some part of the brain itself, we find that the great majority have only one function; the first supplies the organ of smell, and is an *olfactory* nerve; the second supplies the end-organs of the *retina* (where are placed the special bodies by which we primarily get our sensations of light and colour); the third, fourth, and sixth pairs are *motor* nerves only, and go to the muscles which move the eye-ball; while the eighth, in the same way, supplies the ears, and is the *auditory* nerve. Leaving aside the rest, with the exception of the fifth, let us consider in a little more detail its more especial characters (Fig. 5). Sir Charles Bell—to whom we owe the foundations of our knowledge of the difference between sensory and motor nerves—admirably expressed its function when he spoke of it as being the "spinal nerve of the brain." This fifth nerve has, in fine, two branches, one sensory and one motor, as the just-mentioned physiologist was the first to demonstrate. In addition to this, the larger branch, which is the sensory division, has, just like the sensory roots of the spinal nerves, a *ganglion* near its root. It is this upper portion that supplies the organs which yield the sense of touch in the region of the eyes and face, as well as of a considerable portion of the mucous membrane which lines the mouth and the regions lying beyond, in addition to the tongue. To this latter organ it also sends branches for the supply of the special end-organs of taste. It supplies further, by its lower or *motor* half, the muscles which act in mastication. Long thought to be the sole nerve of taste, it is now known to supply all the parts of the tongue nearest the tip, while another cerebral nerve (the ninth of those that arise from some region of the brain) in addition to its other duties supplies the hinder region of that organ.

Putting aside the important lessons which may be derived from the distribution just now very briefly described, we may learn, with regard to the subject that we have more particularly in hand, that the sense of taste is to be distinguished from the other three senses—those of smelling, seeing, and hearing—with the organs for which cerebral nerves are connected, by the fact that it has no special nerve appropriated for its use only. In other words, we cannot speak of a nerve of taste in the same way as we can speak of an optic or an auditory nerve.

It will be unnecessary for us to enter into any account of the general distribution of the ninth or *glosso-pharyngeal*" nerve. Its name, indeed, will indicate this sufficiently enough to those who know that *glossa* is the Greek for tongue, and that the *pharynx* is the hinder portion of the cavity of the mouth. It will be sufficient to repeat that the branches from it which supply the taste-organs of the tongue are sent only to the hinder portions.

When we come to analyse the sense of taste, we fine another kind of difficulty in our way. This sense of taste is so closely associated with that of smell that it is at times difficult for us to be able to discriminate between the effects of these two sensations. We have all seen the refined gourmand who smells the wine on which we ask his opinion, and we all know, to our comfort, that the more

* *See* "Nerves and Nervelessness," CASSELL'S POPULAR SCIENCE, Vol. I., p. 412.

disagreeably tasting drugs which are imposed on us as a punishment for our own imprudence are less nasty when we take them for a "cold in the head" than they are at any other time. However, it is possible to distinguish four sets; there is the bitter, the acid, the sweet, and the salt; and, as Professor Schiff has pointed out, these are probably the only proper names to apply to what are truly sapid substances. It has been demonstrated that what we call the taste of "oily" bodies is really a compound sensation due to the sense of a diminution in the friction between the tongue and the soft palate, combined with a perception of the odour of the fatty body. In support of this proposition it is pointed out that those happy individuals that are unable to *smell* castor-oil are also unable to taste it. Attention may be directed to the experiments of Dr. Romberg, which have shown that in patients affected by the loss of the sense of smell, or who possess it in a diminished degree, there is no sense of taste for any bodies which are not purely bitter, acid, sweet, or salt. Sufficient has been said to show that the sense of taste and the sense of smell are, in their essence, independent; but the relations which exist between them are—except from the more markedly sapid bodies—so intimate that it may perhaps be as well to add another proof. The point to insist upon is that the sense-organs of taste are really capable of exercising their function without any assistance from the sense-organs of smell, this notwithstanding the fact that very commonly a sapid body sends messages to the brain by means of both sets of organs, because we desire to draw especial attention to the proper characters of the terminal organs of the special senses. Dr. Hutchinson observed that in a negro, in whom the sense of smell was altogether lost, sapid inodorous substances were felt by the organ of taste in quite the ordinary manner; and this observation seems to be, of itself, a complete demonstration of the special value of the end-organs, on which we must not be thought to be insisting too much.

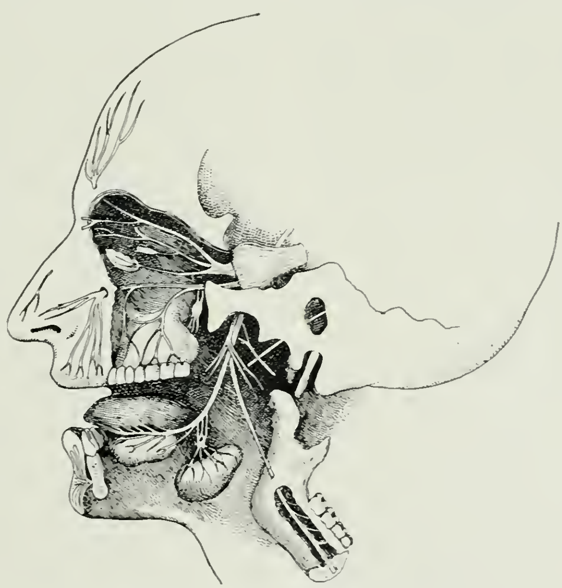


FIG. 5.—THE FIFTH PAIR OF NERVES.

Amongst other duties, this pair of nerves supplies the feeling of taste and conveys this sensation to the brain.

The careful observations of certain foreign physiologists seem to enable us to give a pretty definite account of the regions of the tongue, which are concerned in the sense of taste. The tip appears to be excited only on its under surface; the upper surface is distinctly sensory in the posterior third only, and the edge is provided with a narrow band to which the proper sense-organs of taste are confined. The tongue, however, is not the only region supplied by the gustatory branches of the glosso-pharyngeal nerve; and it is found that the hinder part of that portion of the roof of the mouth which is known as the "hard palate,"

together with the adjoining region of the "soft palate," and the anterior pair of descending prominences connected with this latter are also capable of being excited by sapid substances. Our knowledge of the phenomena of taste is still very far from being complete; but this is, perhaps, largely due to a cause which, it is to be feared, can never be overcome—namely, that sapid bodies to be tasted must be soluble, and soluble bodies become largely spread over the whole area of the mouth's cavity. There have, however, been sufficient observations made to justify, to a great extent, the dogmatic assertion that sweet substances are most easily recognised at the tip of the tongue, acid at the edge, and bitter at the back. Some remarkable results have been attained by the use of an electric current. When we take in one hand one end of a wire connected with a galvanic battery, and apply the other end (*pole*) to the tongue, the sensation of taste is excited. When the so-called positive pole is placed on the tongue, we feel an acid taste; and if the negative is placed on it, we feel the same sensation as is produced by an alkaline body. This observation was, in earlier times, explained by regarding the effect as due to a decomposition by the electric current of the salts contained in the saliva; but it is now more reasonably supposed to be due to the influence of the electric current on the nerves of taste. Temperatures considerably lower than that of the body, or much higher, diminish or destroy the sense of taste; and the common fashion of adding ice, in these days of cheap wines, may, from a physiological point of view, be not unfairly regarded as due to an unconscious knowledge of this fact.

We have now discussed the more prominent facts connected with the sense of taste; as to that peculiarly disagreeable sensation of a long-continued taste in the mouth, nothing of value can be as yet suggested. Little is definitely known as to the structure of the taste-bodies in the insects, although our ordinary observations are sufficient to show us that this sense must be very far from feebly developed in this highly organised group. A German observer has described certain goblet-shaped organs which he has found scattered over the more anterior regions of certain marine worms; and to these, although they are not confined to the cavity of the mouth, he ascribed a gustatory function. In connection with this, it is of considerable interest to point out that there are developed on the lower backboned animals, though more especially in fishes, goblet-shaped organs, which are set in various parts of the skin, and which, in the general opinion of all anatomists, have some higher function than that of mere touch organs. The delicate thread-shaped papillæ of the human tongue are specially modified in some of our more immediate zoological allies. They are considerably increased in size in the dog, who uses them to lick his bones; and in the lion they are of such considerable power that, as Dr. Carpenter remarks, he, "by a single stroke of his tongue, can take off the skin from any part of the human body."

THE WIZARD ELECTRICITY.

VI.—THE TELEPHONE

By FRANK C. WEEDON.

OUR wonder-working wizard is compelled to do many marvellous things in the service of man, but in none of them probably is there such a direct and forcible appeal to the imagination as in the transmission of speech by the electric telephone. The propulsion of horseless carriages, the conveyance of words from one place to another by means of signals in the electric telegraph, the driving of machinery placed at a distance from the engine producing the force, and the harnessing of the power of wind and falling water to produce illumination, each and all, stimulate a feeling of wonder not unmixed with awe at this tireless and mighty agency controlled and directed by civilised man. But in the telephone we have the same sense of mysterious power together with the personal element intermingled. The actual words, pronunciation, accent, and characteristic intonation are conveyed hundreds of miles, and faithfully reproduced. Moreover, the telephone is not limited to the conveyance of a single speaking voice. Melodies, vocal and instrumental, and—what seems more wonderful still—harmonies and other complex sounds, can be borne along by the wires from one place to another.

The telephone is also unusually interesting from another point of view. It offers a remarkable illustration of the invariability of the laws in the natural world, and the perfect confidence we may place in our application of those laws, provided always that our theory and practice are accurate and in agreement.

What, then, are the natural laws which are applied in the making of a telephone? We are all aware that the instrument apparently serves to convey *sounds*, and that in some way or other the power of *electricity* is made use of for this purpose. We will first study the nature of sounds. If a fiddle string is plucked, or a drumhead beaten, we observe two things which go on together. A sound is produced, and the string or drumhead rapidly moves backwards and forwards, or, as scientific people say, it *vibrates*. When the vibration ceases we hear no sound; as the vibration dies down the sound becomes fainter. Sometimes we can hear a sound, but cannot see the vibration. A wine-glass, for instance, when struck will emit a note, but the glass seems quite still. Touch it, however, with a light feather, and its vibrations will be made quite apparent. Touch it so as to stop the vibration, and the note will be no longer heard. Sounds, then, have their origin in vibration. If the vibrating body, however—for instance, an alarum clock—is placed within a glass vessel from which all the air can be withdrawn, we observe that, although the vibration of the alarum gong continues, we no longer hear the sound. It is evident that sound ordinarily travels in the air, and it is possible to show that it is a vibratory movement of the air which conveys it. We should have much less difficulty in understanding this movement if the air were visible. Some idea of the nature of the vibration can be obtained by observing the movement of railway coaches. If a train is at a standstill and the couplings are

slack, then if the engine suddenly moves forward—say six inches—each coach in succession will be jerked forward too. We observe that the snatching forward of coaches passes along the whole train, but each coach is only moved a short distance. If the first coach bumps the engine, the second may bump the first, and so a succession of bumps will pass along from one coach to another. Something like this takes place when air is vibrating and thereby carrying sound. Each particle moves forward and backward through a very minute distance, but the movement is passed on from one particle to the next, and thus the *condition* travels on. When a vibratory motion is communicated from one particle to another, and thus travels along a substance, there is produced what is called a *wave*. It is unfortunate in this connection that our early ideas of waves are often derived from the sea. Standing on the shore, we observe the waves apparently roll inwards, curl, and break, rushing inland sometimes many yards. Thus we may be led to think that a sea-wave is a heaped up quantity of water which moves as one body steadily forward, until it becomes merged in the mass of the ocean or is broken on the shore. That this idea is incorrect may be observed by noting the movement of a floating object at a considerable distance from the land. The floating body will be seen to merely move up and down, showing that *the particles of water do not move forward with the wave*. The nature of wave motion may be illustrated in a still more simple manner. Tie one end of a moderately stout string to a nail in a wall. Hold the other end in the hand so that the string is slightly stretched. Then jerk the hand sideways and observe the string. No portion of the string can travel from the hand towards the wall, but each portion moves sideways, and the total effect is to produce a wave in the string.

Observe that the wave motions in the string and in water are alike in one particular. The motion of the wave is forward or backward, while the movement of the individual particles producing it is up and down or sideways. The railway coaches illustrate a wave wherein the particles move along the same line as the wave front. This is the case with air-waves carrying sound.

Not only can sounds differ in loudness, but also in pitch; that is, some notes are high and others are low.* The actual speed of waves, however, is not affected by the rapidity of the vibrations. Think of a child and a giant walking side by side. The rapid steps of the little one will indicate the short, quick waves of high notes, and the slow, long steps of the giant may be compared to the long, infrequent waves of low notes.

Besides pitch, musical notes have a characteristic quality. It is easy to distinguish between a violin note and the same note produced by a flute. This is because most notes have not only their own proper waves, but others which attend them, producing sounds called by musicians *overtones*. Unmusical sounds are also carried by air-waves, but these are of a highly complex character. *Nevertheless, any particular noise is carried by one, and one only, complex system of air waves, and if, in any manner, we can set that same complex system moving we shall be creating the particular noise in question.* This is the fundamental principle of telephony.

An interesting toy illustrates this fact very well. Two pill-boxes without lids are connected by a thread which passes through the bottom of each box. A knot is tied at each end of the thread, which is then pulled tight. If a person

* *See* "The Sounds we Hear," CASSELL'S POPULAR SCIENCE, Vol. I, p. 542.

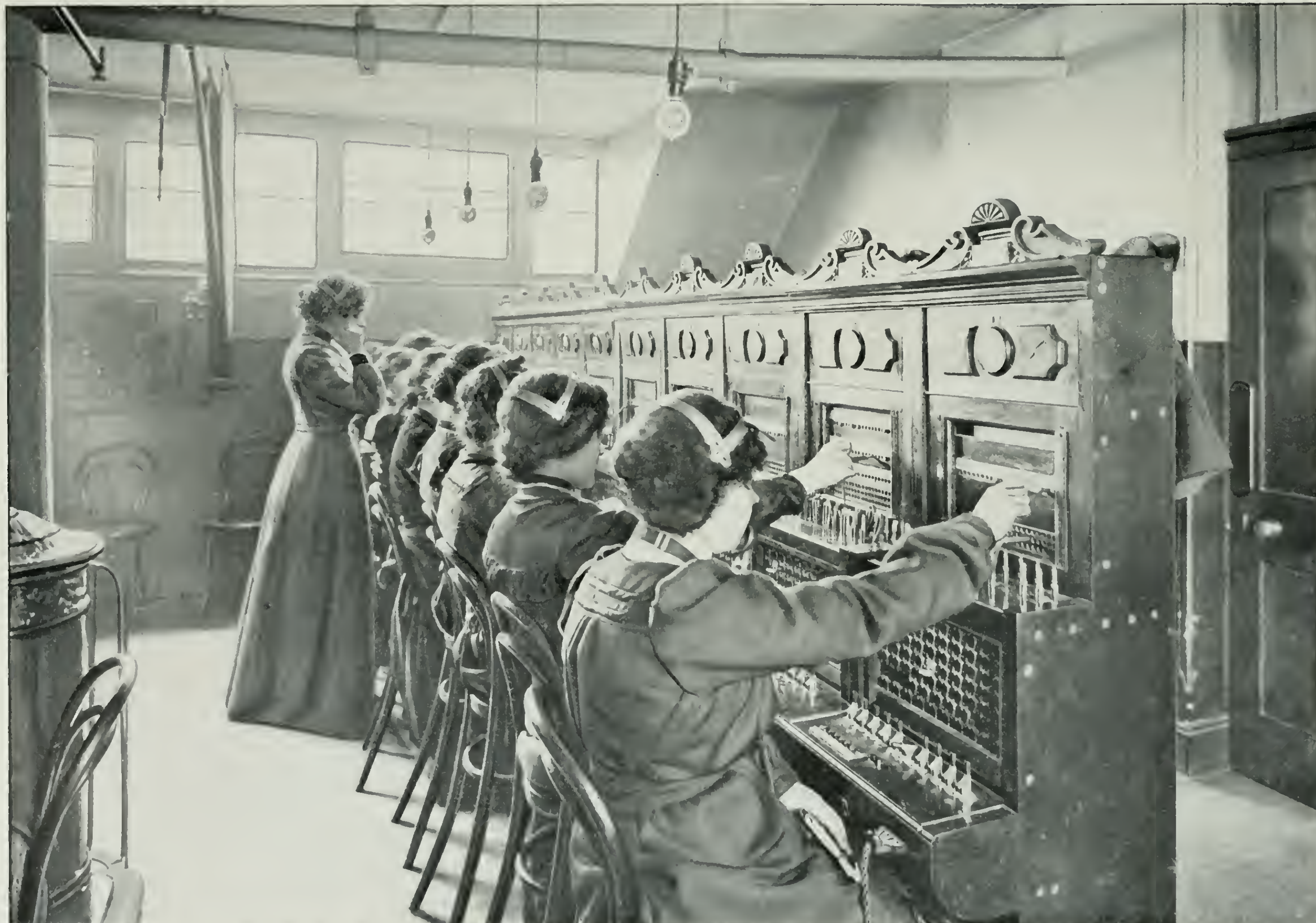


Photo: Cassell & Co., Ltd.

FIG. 1.—OPERATORS AT WORK IN THE NATIONAL TELEPHONE COMPANY'S OFFICES.

at one end of the thread speaks into the pill-box while a second person at the other end puts his pill-box to his ear, it will be found that the sounds can be heard much more plainly than if the instrument were not used. The apparatus is, in fact, a simple form of telephone (Fig. 2).

FIG. 2.—A TOY TELEPHONE WHICH ILLUSTRATES A VITAL PRINCIPLE OF TELEPHONY.

Two pill-boxes are connected by a thread.

The person speaking sets up sound-waves in the air. These fall on the pill-box bottom and cause it to vibrate with the air. The vibrations travel along the thread, and set up similar movements of the second pill-box bottom. This gives rise to air-waves which exactly correspond to the movement of the pill-box diaphragm, and these, falling upon the ear of the listener, convey to him the original sounds.

We need not discuss the imperfections of this kind of telephone; it is introduced here to bring forward the fact that, if at a place, *B*, we can reproduce the waves caused by a sound at a place *A*, then the sound at *A* will be heard at *B*, no matter how this reproduction is brought about.

We will now consider the part which electricity plays in the working of a telephone, and, in order to be quite clear, it is necessary to bring forward several of the great truths of magneto-electricity already dealt with in these pages. In the first place, if a piece of steel is put inside a coil through which an electric current is sent, the piece of steel will be made into a magnet. If the current stops, the steel will retain its magnetic power; and if a current is again sent through the coil the magnetism of the steel will be increased. Another fact, rather more difficult to understand, is the induction of transient electric currents in a coil by variation of magnetic force passing through it. Thus, if we have a magnet close to a coil, the lines of force of the magnet will be linked with the coil. So long as this condition remains unaltered there will be no current produced in the coil; but if *in any manner* we *alter* the magnetic force passing through the coil, we shall induce a current, which will start, stop, reverse, increase, or decrease, according to similar alterations of the magnetic force within the coil.

One more circumstance of importance must be noted. The lines of force always take a definite direction, and continue therein; but if a piece of iron is put in the magnetic field, some of the lines will curl out of their ordinary shape, so as to pass through the iron. Fig. 3 shows the

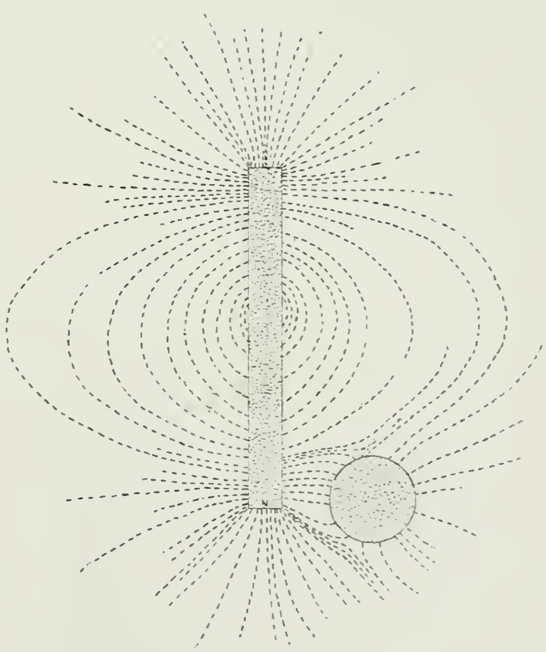


FIG. 3.—LINES OF FORCE FROM A MAGNET DEFLECTED BY A DISC OF SOFT IRON.

distortion of the magnetic field actually produced by putting a piece of iron near a magnet.

Consider what will happen, then, if we experiment with apparatus represented in the diagram (Fig. 4). The lines of force of this magnet, N S, will be linked with the conducting coil, *a b*, and some of them will pass through the sheet of iron, C. If the sheet of iron is now moved towards the magnet, more of the lines will be diverted from their ordinary direction to pass through the iron, and consequently more lines of force will pass through the coil. This alteration produces an electric current in the coil. If the iron is moved away from the magnet, an *alteration* of the number of lines passing through the coil will again be effected, and again there will be an induced current. Increasing the number of lines produces a current in one direction in the coil, and decreasing the number of lines linked with the coil results in an induced current in the reverse direction.

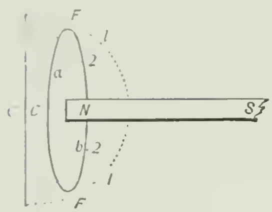


FIG. 4.—THEORY OF THE BELL TELEPHONE.

N. S. poles of magnet. a. b. connecting coil. c. sheet of soft iron.

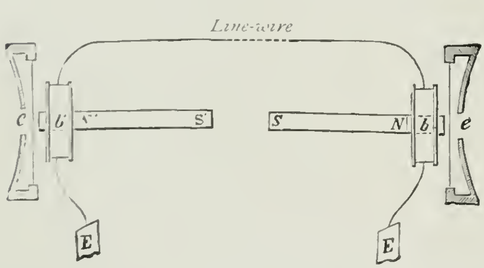


FIG. 5.—TWO BELL TELEPHONES JOINED UP FOR USE.

N S, N' S', poles of two magnets; b b', coil of insulated wire; c c, diaphragm; E E, the earth.

We have now cleared the way for an explanation of the working of the well-known Bell telephone. In Fig. 5 there are two magnets, N S and N′ S′, each having close to one end of it a coil of insulated wire, *b* and *b′*. These coils are connected to each other and to the earth, which is an electric conductor, so that a current set up in one coil can pass along the wire, through the second coil, and back again *via* the earth. In front of each coil is a sheet of thin sheet-iron, *e e*. If sound-waves fall on *e*, the iron diaphragm is caused to vibrate; this rapidly increases and decreases the lines of magnetic force linked with the coil at that end. Consequently, induced currents, alternating in direction, are produced; and these, flowing through the second coil, correspondingly increase and decrease the magnetic pull on the second sheet of thin iron. The result is that this second sheet-iron diaphragm is set in rapid vibration by the variation on the magnetic attraction, and hence it gives rise to air-waves exactly similar to those which impinged on the diaphragm at the distant end, and the original sound is reproduced.

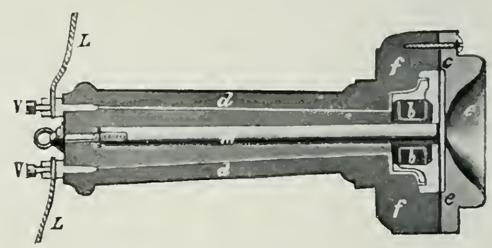


FIG. 6.—VERTICAL SECTION THROUGH A BELL TELEPHONE.

m, magnet; b b, coil of wire; c, diaphragm of soft iron; d d, casing; L L, wires; V V, terminals.

(By permission of the General Electric Company.)

There would at first sight seem to be no limit to the distance across which sound could be conveyed by such an arrangement. But the electric force "tires" when the current flows through a long conducting wire, and the reproduction of sound is feeble unless the two telephones are comparatively close together. Fig. 6 shows a vertical section through a Bell telephone, and in Fig. 7

we see the instrument as it is sold to-day.

It is to Professor Hughes that we are indebted for the discovery that made it

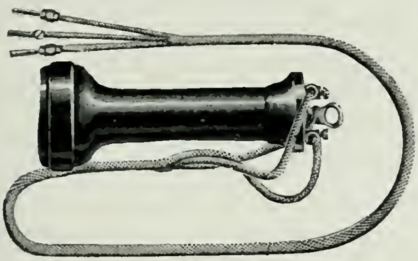


FIG. 7.—EXTERIOR VIEW OF A BELL TELEPHONE.

Compare with Fig. 6.

possible to use telephones over far greater distances than a pair of Bell's instruments could bridge. He found that if there are loose contacts in an electric circuit, the resistance of that circuit will be altered when sound-waves fall upon those loose contacts. If a single Bell's telephone is included in such a circuit, then when sound-waves strike the loose contacts the resistance will correspondingly vary, and the current flowing in the circuit will proportionately fluctuate. The result will be a variation in the magnetic attraction on the diaphragm, which will accordingly vibrate and reproduce the sounds causing the alteration of resistance. Such an arrangement can be made exceedingly sensitive to small sounds, and is consequently called a *microphone*. Two simple microphones are shown in Figs. 8 and 9.

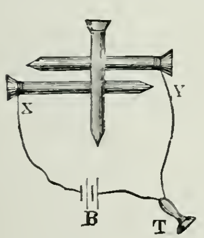
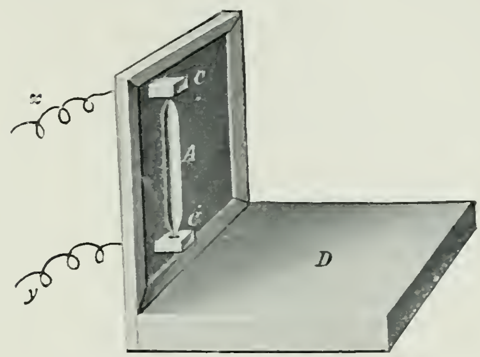


FIG. 8.—HUGHES' SIMPLE MICROPHONE.

The current from the battery, B, passes through the junction formed by the nails, X Y, through the coil in the telephone T. Sound waves falling on the nails alter the resistance and cause corresponding sounds to be heard in T.

In Fig. 8 the battery circuit is completed through a Bell's telephone and ordinary French nails, two of which are parallel to each other and connected by a third simply laid across them. The alteration of resistance takes place when the sound-waves fall on the crosswise nail, thereby altering its contact with the other two. The other microphone (Fig. 9) is also a very simple contrivance. A very satisfactory instrument can be made from a piece of ordinary lead-pencil sharpened at both ends, the black-lead points fitting loosely into recesses in two carbon blocks glued to an upright thin board. The sound-waves fall upon this board, and cause it to vibrate, thereby altering the contact at *c* and *c'*. The



IG. 9.—HUGHES' CARBON MICROPHONE.

Sound-waves striking the upright board set it in vibration, thereby altering the contact of the carbon A, at C and C'. This alters the electric resistance and reproduces the sounds in a receiver placed in the circuit. x y, connecting wires.

(By permission of the General Electric Co.)

alteration in electric resistance which can thereby be produced is made use of just as in the case of the French-nail microphone already described.

We may here note that in a telephone circuit there are always two instruments—one into which a person speaks, called the *transmitter*, and the other at which one listens, called the *receiver*. When both receiver and transmitter are Bell telephones, no battery is needed. If the transmitter is a microphone, a battery is required.

These simple microphones are sensitive, not only to the sounds intended to be conveyed, but to other external sounds as well, and they are not used in practical telephony. Many forms of microphone

transmitters have been invented, and the Hunningscome Deckert, the instrument which has been greatly used by the General Post Office and the National

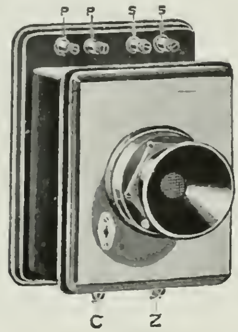


FIG. 10.—THE HUNNINGSCOME DECKERT MICROPHONE TRANSMITTER.
(By permission of the General Electric Co.)

Telephone Company in this country, is illustrated in Fig. 10.

The funnel-shaped mouthpiece directs the sound-waves to a thin disc of carbon. A second carbon plate has its surface cut into small pyramids, and the space between the two carbon plates is filled with carbon granules, which are prevented from settling down or clogging by the pyramids already mentioned. The thin disc vibrates under the impact of the

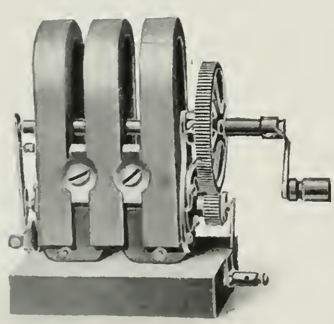


FIG. 11.—A MAGNETIC RINGING APPARATUS: PRACTICALLY A SMALL DYNAMO.
This is used to ring the signalling bell.
(By permission of the General Electric Co.)

sound-waves, pressing and releasing the carbon granules, and causing that variation in electrical resistance which is the fundamental principle in microphone transmitters.

Microphone transmitters have made it possible to telephone over greatly increased distances, but it is evident that, as the resistance increases with the length of wire used, if the line is very long some means must be found of supplying high electromotive force to the circuit. Instead of using a large battery of very many cells, an induction coil is generally employed. In order that two persons may hold conversation over a considerable distance it is usual to employ two microphone transmitters, two Bell receivers, and an induction coil.

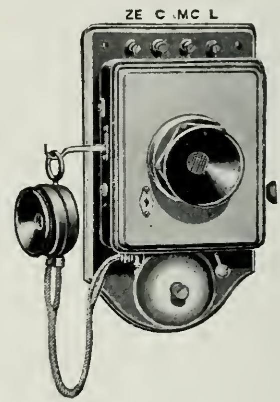


FIG. 12.—A COMPLETE TELEPHONE AS USED TO-DAY.
The person wishing to use it presses the button on the right. This "rings up" at the other instrument. Then he unhooks the receiver on the left, places it to his ear, and speaks into the micro-phone transmitter in the centre.
(By permission of the General Electric Co.)

These are the essential parts of a simple telephone circuit. There are certain accessories, however, if the instruments are to have any practical value, and the more obvious of these I will now describe.

It is quite clear that if the circuit were left closed the battery would run down and have to be renewed; and, secondly, some means of attracting the attention of the person at the distant end of the line is wanted. An ordinary electric bell can be used for this latter purpose, or a magnetic ringing apparatus, practically a small dynamo, may be employed (Fig. 11).

To prevent the wasting of the cells, the instruments are made so that unless the receiver is in use the circuit is open. This is effected by means of an automatic switch-hook, which, when the receiver is attached to it, opens the battery circuit. When the receiver is removed the switch closes the circuit, and telephonic communication can be established. It is further arranged that closing the circuit for telephonic talking also cuts out the bell apparatus. Fig. 12 shows a telephone with a battery call apparatus, and Fig. 13 illustrates a telephone with magnetic call apparatus. To call a person with the first instrument it is necessary to press the button seen in Fig. 12, while with the second instrument the handle must be turned. When it is desired, as in a factory, that several persons at as many different points shall be in intercommunication, then special arrangements have to be made with switches and *annunciators*. It may become necessary to connect each telephone with a central office or exchange (Fig. 1), wherein connections may be made as required.

It is possible to make use of the earth to complete the telephone circuit, and this may be done with small private installations. For commercial purposes over considerable distances a complete metallic circuit of copper wire is provided.

It is not difficult to see that the sounds of the transmitter will be heard most clearly in the receiver when there is no drag upon magneto-electric action, and that telephony over long distances presents certain difficulties. In the first place, the ordinary resistance of the wire results in a weakening of the electric force, rendering the sounds heard in the receiver indistinct. This, as we have seen, is met by the use of induction coils. Another formidable difficulty is, perhaps, not so self-evident, and that is the electric action that takes place *outside* the wire. The "up" and "down" lines, with the space between them, form what is known as a "condenser," and the electric energy is poured into this intervening space when currents are sent along the wire. The closer the two wires are together the greater is this effect, and the greater is the consequent clogging produced. In a cable the two wires are close together, and the result is that, while with separate overhead wires telephonic connection is made between New York and Chicago (a distance of 950 miles), it is difficult to telephone over a tenth of that distance along underground or submarine cables. A recent invention of Professor Pupin promises to greatly extend the distance over which telephony is possible, so that the time may not be far distant when it will be possible to speak between London and New York.

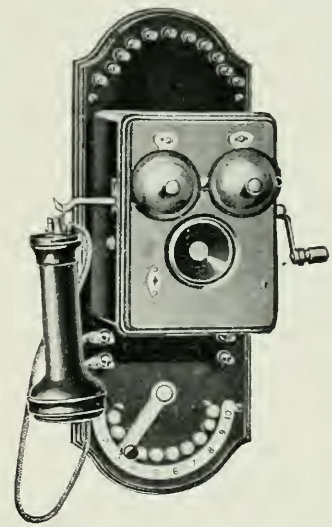


FIG. 13. — WALL PATTERN MAGNETIC INTERCOMMUNICATION TELEPHONE.

The working of this instrument is the same as that shown in Fig. 12, except that to "ring up" it is necessary to turn the handle shown on the right.

(By permission of the General Electric Co.)

A method of telephoning without an electric circuit, by means of a *photophone* (Fig. 14), is a matter of considerable scientific interest, even if not yet of much commercial importance. In this apparatus

advantage is taken of the remarkable property of selenium of varying its elec-

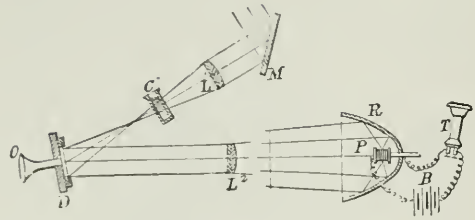


FIG. 14.—TRANSMISSION OF SPEECH BY PHOTOPHONE.

B, battery; T, bell receiver; O, transmitter; D and R, mirrors; P, selenium; L, lens.

trical resistance according to the *light* falling upon it. Accordingly, the transmitter is a thin mirror, D, from which a powerful beam of light is reflected in pulsations according to the vibratory movement of the mirror when the sound-waves fall on it. The rays of light thus reflected fall upon a collecting mirror, R, and are condensed upon the selenium, P, which is in a simple electric circuit with a Bell receiver, T, and a battery, B. The resistance of this circuit, being altered by the fluctuations of the light falling upon the selenium, varies according to the movements of the transmitter mirror.

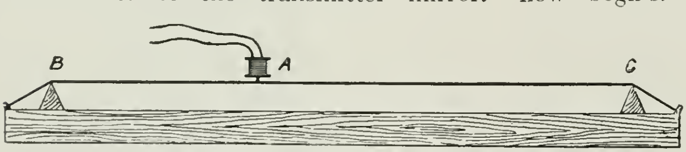


FIG. 15.—A SIMPLE FORM OF TELEGRAPHONE.

B C is a piano wire; A, an electro-magnet.

The result is a varying electric current in the receiver circuit. This method of "speaking along a beam of light" would seem especially useful where it is difficult to maintain cable communication.

This article would be incomplete if it omitted a recent invention of Herr Valdemar Poulsen, the *telegraphone* (Fig. 18). In a very simple form of the apparatus described by the inventor a steel wire (5 feet long and $\frac{1}{50}$ inch in diameter) is stretched over two supports, C and B (Fig. 15). A small electro-magnet having a core of soft iron rod, $\frac{1}{3}$ inch long and $\frac{3}{100}$ inch in diameter (Fig. 17), is put "in series" with a microphone and a battery. If sounds are made close to this microphone, the electrical resistance of the circuit will correspondingly alter, as already described. The result will be a varying current flowing round the coils of the electro-magnet, and in consequence the electro-magnet will rapidly alter in

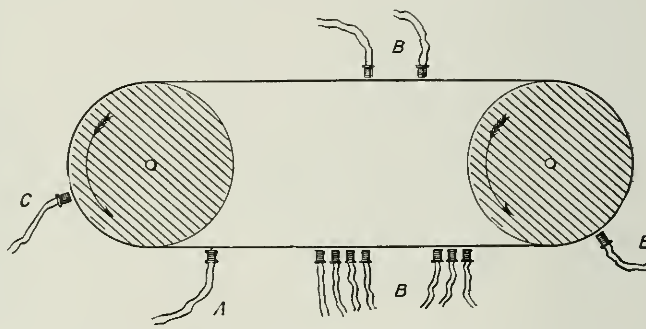


FIG. 16.—DIAGRAM SHOWING HOW ONE SPEECH IN THE TRANSMITTER AT *A* MAY BE TELEPHONED SIMULTANEOUSLY IN MANY DIRECTIONS BY RECEIVERS CONNECTED WITH *B*, *B* AND *C*.

attractive power. All this has previously been dealt with, but the beautiful part of Herr Poulsen's work now begins. While the electro-magnet is varying in power, according to the sounds heard in the microphone transmitter, it is moved along the steel wire from C to B. The steel wire is thereby magnetised, and because of the fluctuation in the strength of the magnetising force the magnetic

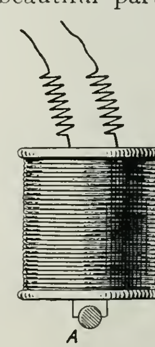


FIG. 17. — ENLARGEMENT OF ELECTRO-MAGNET IN FIG. 18.

The disc at A is a vertical section through the wire, and it is enclosed by the hollowed end of the electro-magnet.

condition produced is irregular, or, as it has been described, it is "lumpy."

The microphone and battery may now be removed, and in place a Bell receiver may be substituted; or another and similar electro-magnet may be used with the Bell receiver only in its circuit. The electro-magnet is again moved along the wire from A to B, and, in consequence of the irregularity of the magnetic condition of the wire, the number of lines of force linked with the coil of the electro-magnet will be varying, and corresponding currents will be induced. As a result the receiver will emit the sounds previously transmitted by the microphone.

It is evident that this instrument is a combination of *gramophone* and *telephone*. The records in the steel wire are reported to be very durable, and the quality of the sounds given out is wonderfully good. It must surely be counted among the marvels of applied science that by this instrument human speech can be stored up by an irregular magnetic condition of a steel wire. If it is desired to remove a record from a wire, the necessary procedure is quite simple. Pass a strong magnet over the wire, and it is "cleaned"—that is, it is ready for a fresh impression.

The simple stretched wire is not sufficiently long for many words to be recorded on it, and in the ordinary instrument it is wound in spiral grooves on a revolving drum (Fig. 18). A mechanical arrangement is made whereby the wire passes under the pole of the electro-magnet as the drum is revolved. An ingenious adaptation of the instrument for the purpose of transmitting the same messages to several different receivers is represented diagrammatically in Fig. 16.

A steel band receives the record as it passes before A, being caused to travel onwards by the motion of the two rollers. Electro-magnets, B and C, convey the record to the several receivers, and the wire eventually passes before a strong magnet, there to be "cleaned," and so made ready for further use.

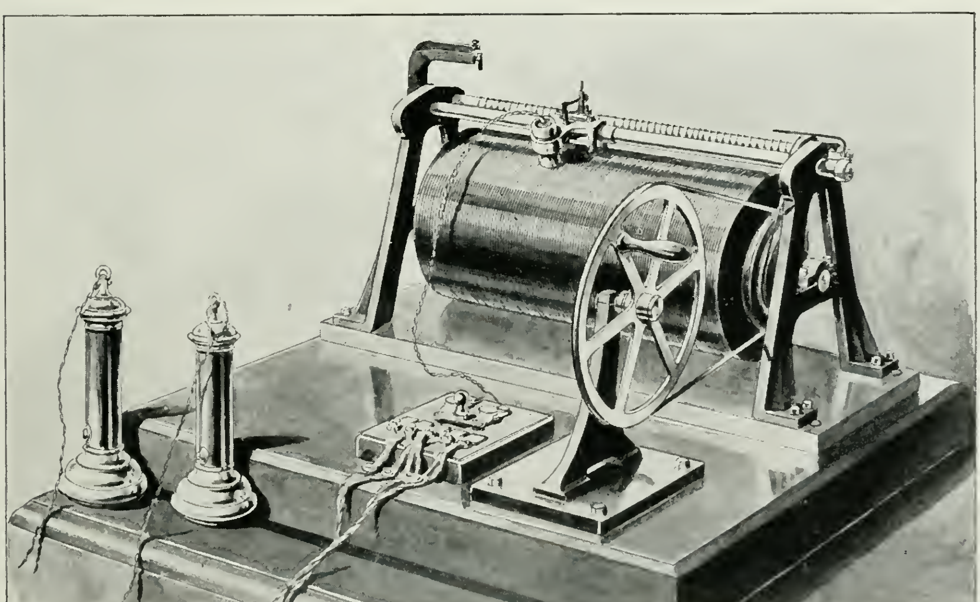


FIG. 18.—POULSEN'S TELEGRAPHONE.

The wire is wound on the drum, and when the handle is turned the electro-magnet passes over the whole length of wire, recording in it the sounds falling upon the transmitter.

HOW A FISH SWIMS.

THE term "swimming," as it is used in ordinary conversation, is a very indefinite one, and it is by no means always applied to the right objects or to the proper occasion. Before we take up the subject of this paper, as to how a fish swims, we must, therefore, come to a clear understanding as to what is meant by swimming.

We say that a boat, or even a piece of wood, swims, although the word "float" would be better employed in this case; for by floating we generally understand the mere lying of a body on the surface of the water in opposition to its not sinking to the bottom. This motionless floating does not apply to a fish; but there are many cases of actual progress or motion of animals in the water concerning which we use the word "swimming" in the proper and full sense of its meaning. Thus, a duck, a horse, or man himself, swims when supported by the water, and, therefore, when partly floating; by the help of their feet or arms, progress is made through this element. But there is a great difference between the swimming of such animals and that of a fish; because the former, as air-breathing creatures, have, as long as they are swimming, to fulfil two duties: first, they have to prevent themselves from being drowned, or, in other words, to keep their heads, or at least their nostrils, above the surface of the water; secondly, they have to make their way through it either in search of food or in order to get out of the water as soon as possible. The latter is the case with many quadrupeds, such as hares or cats, which, although not at all devoid of the power of swimming, are well known for their antipathy to water. Again, a hedgehog, if thrown into the water, will float for a time, and even make some progress; but it speedily drowns, because it persists in keeping its nose under water. This behaviour can scarcely be called swimming.

The fish, on the other hand, is quite in a different position. The water is its home, and moreover, as it is provided with gills, there is no fear of its drowning; thus it does not float like the above-mentioned animals *on* the water, but *in* it.

Of course, we all know that there are many invertebrate animals equally fit for living in the water, and some—as, for instance, the so-called jelly fish and the cuttle-fish—can even make fair progress through the sea; but there is no other class of animals which combines such a high rate of speed with such graceful motion as a fish. Whether near the surface of a raging sea, or in the vast abyss of the still ocean; whether in the calmness of the inland lake, or buffeting the rush of a mountain torrent—wherever there is water, there we find fish.

We will now, therefore, glance at the structure of these wonderful creatures.

Let us take, as an example of a typical bony fish, the well-known salmon, a perch, or a carp. The salmon is extremely well fitted for cutting through the water at great speed. The body in its general shape may be compared to a wedge, the thick end represented by the head, the sharp edge by the fin of the tail. A transverse section through any part of the body is of oval shape, broad near the back, narrow towards the belly.

This wedge shape of the body is of great advantage to a fish which requires to swim rapidly, as after the latter has

got momentum the currents of water produced by the onward motion of the body rush against its whole surface, and thus must press the animal forwards. The fish, therefore, resembles a wedge driven into the cleft of a piece of wood, the pressure of which upon the long sides of the wedge has the tendency to make the latter slip out in the direction of its thick end, and would certainly do so if the wedge were made slippery by some greasy substance. Another advantage of the heavier part of the body, or centre of gravity, being nearer the head than the tail will be apparent if we remember that a similarly shaped body — for instance, the root of a carrot—when thrown into the air, will always turn its thick end forwards and the tapering point of the root backwards.

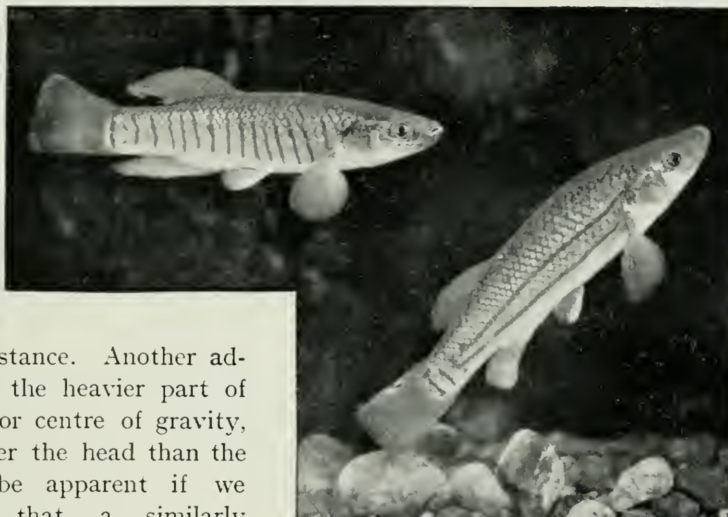


Photo: Myron W. Stickney.

FIG. 1.—*FUNDULUS MAJALIS*, AN AMERICAN FISH OF ACTIVE HABITS, AND POSSESSING GREAT TENACITY OF LIFE.

The outer surface of a fish is, as is well known, extremely slippery, the scales being directed backwards and closely pressed to the body. There is nothing that could produce any resistance against onward or head-forward motion.

The tail ends in a vertical fin, which is supported by numerous fine and elastic rays of bony matter. It is furnished with very powerful muscles, which are arranged along the sides of this organ, and can bend it forcibly to the right or left, while the up and down motion of the tail is very limited.

The other fins are divided into two kinds—the unpaired or vertical fins, and the paired, lateral, or horizontal fins. All the fins are supported, like the tail fin, by bony rays, and can be erected or spread out and closed or laid down in a fan-like fashion.

Of vertical fins we have, besides the tail fin, the dorsal or back fin; and on the ventral or belly side, in front of the tail, a generally short anal fin.

The lateral fins are one pair just behind the head, which, as a rule, are the largest and broadest—the *pectoral* fins, equivalent to our arms; and one smaller pair, the ventral fins, which in the salmon or carp are situated near the middle of the trunk on the ventral side.

These two pairs of fins are the four limbs of the fish, and have muscles attached to their roots which enable them to be spread out or closed, and to be moved obliquely, up and down, forwards and backwards.

This is the typical arrangement of fins, but it must be borne in mind that, if we take the whole class of fishes, the fins are subject to as great variations in form and size as the animals themselves. Any

of the above-mentioned fins may be altogether absent, or, as is the case with the pectorals in the flying-fish, may attain an extraordinary development. The rhomboid shape of a ray is due to the enlargement of the pectoral fins. The ventral fins may be removed from their backward position, and be situated just behind or even in front of the pectorals, on the throat, as in the gurnards. The dorsal fin is either very long or short, high or low, or it is split into two or three, as in the codfish. In the eel the dorsal and anal fins are very long, and are united with the tail fin, forming a vertical fringe round the greater part of the body.

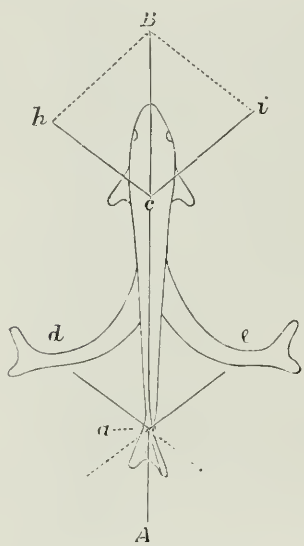


FIG. 2. — THE ACTION OF A FISH'S TAIL IN SWIMMING.

A, B longitudinal axis of fish.
c, centre of gravity.
d a, e a, propelling strokes.
Note that e a is parallel to i c and d a to h c.

The centre of gravity of a fish is situated above the centre of its body; its equilibrium therefore is unstable, and the animal has a tendency to turn belly upwards, as when dead. How this tendency is neutralised we shall see presently.

Now, the explanation of the progression of a fish might seem obvious enough, because one might think that the four lateral fins are used like oars, by paddling the body of the fish forwards, and that the tail fin and tail, like a rudder, are directing its course.

But this is by no means the case, and a thoroughly satisfactory explanation of how a fish swims has not yet been discovered, as in the various theories hitherto started there still remain some doubtful and puzzling points.

The progress of a fish through the water is not due to its fins, but the principal organ of motion is the powerful tail, which, as we can observe in any fish kept in a vase, makes alternately strokes to the right and to the left side.

If A *c* B (Fig. 2) be a line going through the longitudinal axis of a fish, with its centre of gravity in *c*, the tail-fin when at rest will be at the point *a*. If the fish suddenly lashes out with its tail to the right from *a* to *e*, the pressure caused upon the water by this lash is equally felt by the tail, and is transplanted to the centre of gravity *c*, with the effect of turning the fore part of the fish to the right, just in the same way as a rudder when turned to the right brings the bow of the boat round to the same side.

If the fish strike back from *e* to *a*, the motion of the fore part will be reversed to the left, and at the same time will be urged obliquely forwards in the direction of *c h*. If the same lash of the tail be repeated on the left side, the head will be pushed in the direction of *c h*. Both these strokes of the tail, from *d* to *a* and from *e* to *a*, according to the parallelogram of forces, will send the fish forwards in the diagonal of the parallelogram *c h* B *i*. This is *c* B in the direction of the longitudinal axis of the fish.

As both the strokes cannot be delivered at the same moment, but first the right and then the left one, or *vice versâ*, of course the fish does not travel in a straight

line; but, now being pushed somewhat to the right (*i*) and then to the left side (*h*), describes a wave-like track. This can easily be noticed if we watch a fish when swimming leisurely.

According to this theory, which was first brought forward by the great Italian mathematician Borelli, the fish, by the action of its tail, proceeds in precisely the same way as a boat is sent through the water by a single oar passed over its stern and handled obliquely alternately to the right and left side, in a manner which we know as "sculling."

There are, however, several difficulties in this theory. The tail, while being moved from *a* to *e* (non-effective or back stroke, as this is called by the authors), becomes curved, with the concave or biting side, *e*, directed forwards; while during the forward or effective stroke from *e* to *a* the convex surface, and therefore the more resisting one, presses against the water. The motion of the tail from *a* to *e*, of course, retards the progress of the fish, just as frequent use of the rudder lessens the speed of the vessel.

Photo: Myron W. Stickney.

FIG. 3.—WHITE PERCH (*MORONE AMERICANA*).
From a photograph of the fish in water. Note the stiff dorsal fins.

Now, if we suppose the force resulting from the flexion of the tail to equal that of its extension, there would be no progress of the fish whatever, as both the back and the forward motions neutralise each other. Moreover, if the flexion of the tail be more effective than the extension —and this would certainly be the case if both the strokes were made with the same force, as the back stroke has the advantage of the biting surface—there would be a retrograde motion, and the fish would go backwards from *c* to A. But as the fish swims forwards by the aid of its tail, either the theory of the sculling motion of the tail must be incorrect or there must be some further explanation of the discrepancy between theory and practice.

There are, indeed, at least four circumstances which would cause the extension stroke to have a surplus of power, and would explain the difficulty.

Firstly, the tail, while making the outward stroke from *a* to *e*, may move less rapidly than when lashing from *e* to *a* or from *d* to *a*.

Secondly, the fin of the tail during the outward stroke is either folded or less expanded, while during the extension or inward stroke the caudal fin is kept rigidly extended. Moreover, the muscles of the tail incline its broad plane and that of the terminal fin to the direction of its sideward motion, while as it passes towards *a* they present their whole plane perpendicularly to the line A B. This inclination, combined with a partial folding and expanding of the fin, would enable the tail to strike more powerfully in the direction towards *a* than from the line of progression.

Again, the fish, when once in motion, causes a current behind it in the direction from A to B; this current offers comparatively but little resistance to the tail during its outward stroke, whilst the reverse stroke towards *a* meets with a much greater resistance, and thus makes this stroke more effective than the other.

The above considerations will give a sufficient explanation of the *slow* onward progression of a typical fish, like a salmon, perch, or carp, the slow motions of the tail of which we can easily watch.

But there are other fishes to which this theory is not applicable. This was first pointed out by Professor Pettigrew. He observed that in the sturgeon, the movements of which are very slow and deliberate, the whole body in swimming is always thrown into two curves—one, the *cephalic* curve (as he terms it), made by the anterior half of the body; the other, a caudal one, by the tail. These two curves are opposite to each other, the convex surface of the one looking to the right, that of the other to the left, as is seen in Fig. 4. This enables the sturgeon during the flexion of the tail from the line *a b* towards *e* to present always the convex or less resisting side to the water, whilst during the extension of that organ its biting or concave surface is acting. During the extension of the tail, when it is travelling towards the middle line *a b*, the "cephalic" curve balances, so to speak, the "caudal" one, and the head travels over the line *a b* towards *i*. When the tail is extended it is immediately thrown over to the left side towards *d*, and the cephalic curve to the right; the fish is then in the position indicated by the dotted lines.

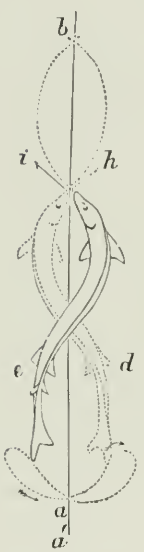


FIG. 4.—SWIMMING OF THE STURGEON, SHOWING CURVES OF BODY AND TAIL.

The dotted lines from a show the curves in which the tip of the tail moves. References as in Fig. 2.

Thus the tail may move from side to side with the same rapidity during both strokes, and as the animal always strikes the water with the biting or concave surface during the extension stroke (which, as we have explained before, produces the forward motion), and with the convex side during the flexion stroke, the former has constantly an enormous advantage over the latter—the resistant force of a concave body to that of a convex one under the same conditions being in the ratio of two to one.

Another advantage of this kind of swimming is that, although the tail is moved rapidly from right to left, the tip always remains nearly in the line of progress, *a b*, and so greatly assists in steadying the course of the animal.

Again, during the flexion of the tail the caudal fin is not kept in a plane, but is curved in two directions—let us say, the upper end to the right and the lower one to the left—and the tail itself with this curved fin is slightly inclined to the side of its flexion.

When near the middle line the tail, of course, is straight, and so is the plane of its fin, kept perpendicularly in the same line. After the tail has passed the latter all the positions are reversed. Now, it is clear that as by the flexion of the tail the fin is drawn forwards from *a* towards *a* (Fig. 4) the fin is caused to press with oblique planes against the water and act like a ship's screw. It is, however, far better than such an artificial screw, because when passing the line *a b* the position of its blades is immediately reversed, and as long as they are in the middle line they are kept straight, and do not offer any resistance to the water; whilst the screw of a ship, without exception, is under the great disadvantage that a considerable portion of the force exerted by its blades upon the water is directed backwards, and that the screw if revolved beyond a given speed ceases altogether to be effective.

In a similar way as is described in the sturgeon all those fishes move which,

like the eel, are of a greatly elongated form, and which, as a rule, have their tail surrounded by a very long but low fin. Such fishes bend their bodies in several curves, but always in an even number, so as to compensate or to balance each other.

Again, not only the long and slender fishes, but also the shorter and stoutly built ones, like our carp and perch, if they want to swim quickly, make undulating motions with their bodies. The only difference is that the fore part of their body can scarcely undergo any visible bending. If we watch such a fish when in quick progression, we see the hinder half of its body rapidly thrown into short undulating curves, which seem—as it appears to the looker-on—to come out of the trunk, and are directed towards the end of the tail. As these undulations are smaller towards the trunk, as the less flexible part of the fish, and greatest on the blade of the caudal fin, which, as described above, they whirl in a screw-like fashion, all the continuous pressure against the water is directed backwards. This force, being transplanted to the body of the fish, drives the latter on in the opposite direction, head forwards.

The screw-like motion of the tail is also used amongst mammals—by the whales and by the manatee. However, we must remember that in these animals the two blades of the tail, or the "flukes," as they are called, are not placed vertically, but lie horizontally, and consequently the strokes are delivered in an up-and-downward direction. A whale, according to Beale, when undisturbed, passes tranquilly along just below the surface of the water at about three or four miles an hour, which progress he effects by a gentle oblique motion from side to side of the flukes. When desirous of proceeding at a greater rate, the action of the tail is materially altered. Instead of being moved laterally and obliquely, it strikes the water with the broad flat surface of the flukes in a direct manner, up and downwards. As Dr. Murie first observed, the lobes of the tail, when dried, "assume opposite concave-convex curves, so as to produce a very close resemblance, both in curve and angle, to the blades of a screw-propeller"; and in the museum of the Royal College of Surgeons, in London, there are preserved the extremities of the tails of several dolphins, which, after being dried, remain in this position. This seems to prove that the whale bends the flukes into the same shape, and, therefore, that the mere act of striking up and downwards of the tail would produce a screw-like action, and drive the animal forwards in the direction of its longitudinal axis.

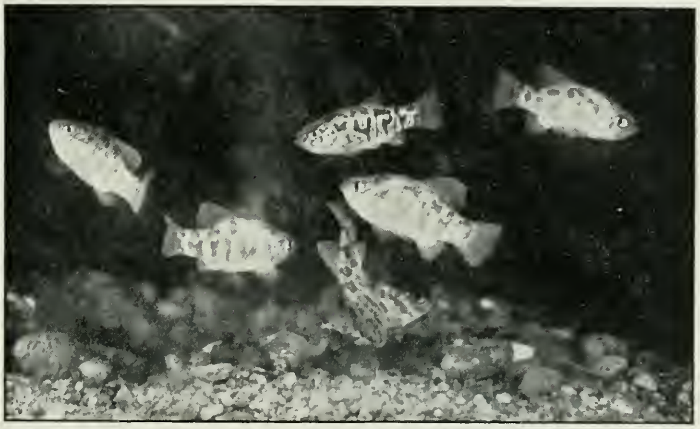


Photo: Myron W. Stickney.

FIG. 5.—VARIEGATED MINNOWS IN A TANK.

But this is not the only use of the tail. If the fish, when progressing through the water, keeps the tail bent to the right or

to the left, with the concave side directed outwards, it will turn to the same side, and the tail therefore acts precisely like a ship's rudder. Again, many fishes, by giving a single forcible stroke to the water with their tail in a vertical direction, throw themselves out of the former. This they do for many purposes—either to catch an insect which flies over the surface, or to evade the voracious mouths of their enemies, such as sharks, pikes (Fig. 9), dolphins, and other ravenous inhabitants of the deep. The salmon is well known for the jumping power of its tail, by the help of which it is enabled to overcome the various obstacles in a river, as weirs or bars. The height of such a leap, although often greatly over-estimated, is known for certain frequently to amount to more than six feet.

Hitherto we have only spoken of the progression of the fish in the direction of

FIG. 6.—THE SEA-HORSE (*HIPPOCAMPUS BREVIROSTRIS*).

its longitudinal axis, and many of my readers will be astonished that they have not heard even a mention of the other fins. As there exist no fishes which are absolutely without fins (for if the paired ones are greatly reduced the vertical ones are more developed, and *vice versâ*), it

Photo: Myron H. Stickney.

FIG. 7.—SEA SQUID TURNING.

The squid is not beautiful; but he is interesting, if clumsy.

follows that the fins must naturally be of great service to the fish.

The main function of the fins—with the exception of a few particular cases where they are really propelling organs, as we shall see later on—is to balance the fish's body and to steady its course. It will be easily understood that the vertical dorsal and the anal fins, as they lie precisely in the longitudinal axis of the body, must find their representatives in the keel of a ship, and thus accomplish the same purpose as that mechanism.

The paired fins act in a similar manner, for by moving slightly up and downwards they balance the body and keep it at the same level above the bottom.

This has been proved by experiment. A fish deprived of its pectoral fins sinks down with its fore part, and assumes an oblique position. If the pectoral and the ventral fins of one side — for instance, those of the right—are removed, the fish rolls over to the right; and if deprived of the fins altogether it turns completely round, belly upwards, like a dead fish, in which, of course, the fins have ceased

to act. If its dorsal and anal fins are cut, the course of the animal assumes a zigzag and very unsteady line.

A few down strokes of the pectoral fins will raise the fore part of the fish, and will bring it nearer to the surface. If only the right fin be used, and make a few down strokes, the creature will turn over to the left, and will take the oblique position characteristic of a shark when about to seize its prey. Again, the backward striking of the right fin, whilst the other one is compressed to the body, will wheel the fish round to the left. In fishes which, like the sharks, swim near the surface of the ocean, and which therefore have often to deal with the force of waves, we see all the fins, including that of the tail, well developed and more strongly constructed than in other fishes which live near the bottom of the sea or prefer the calm fresh-water lakes.

Whilst inquiring into the action of the paired fins, we must further bear in mind that they are placed in different positions in different kinds of fishes. Thus, in the shark their planes are more or less horizontal, and consequently their strokes are generally delivered in an up-and-down direction; whilst in the carp the pectorals are more removed from the ventral side, and inserted nearer the lateral line, with their planes standing almost vertically; therefore the strokes of such fins will be delivered backwards and forwards, and can, if necessary, add to the progression by paddling like the oars of a boat.

Many fishes—as, for instance, the rays and sharks—do not possess an air-bladder (Fig. 8), which is a proof that this organ, the purpose of which has been so much contested, is not essential for swimming. In the vast majority of fishes, however, the air-bladder lies in the cavity of the body between the back-bone and the intestines, and is filled with gases of various composition. Its shape and size are subject to the greatest variation. In many fishes the air-bladders open by a duct into the intestinal canal, and thus may be partially emptied; in others there is no aperture whatever.

In many fishes the walls of this organ are furnished with muscles which can compress the air-bladder and diminish its size, so that the specific gravity of the fish, which is nearly that of pure water, becomes greater. The fish in this case will sink. If the air is pressed into the anterior cavity and the hinder one partly emptied, the centre of gravity is shifted backwards, and the fish will assume an oblique position, with its head rising, and *vice versâ*. In this way the presence of an air-bladder must greatly assist the fish in its motions; but it must be remarked that this hydrostatic use of the air-bladder may only have been fortuitous, and that its main purpose may be for some kind of respiratory function.

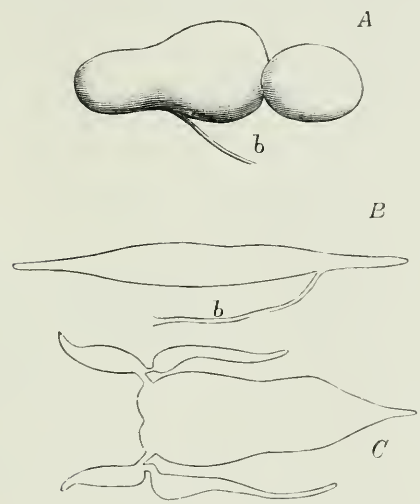


FIG. 8.—AIR-BLADDERS, IF NOT NECESSARY TO, GREATLY ASSIST SWIMMING.

A, air-bladder of common carp (Cyprinus carpio): b, the duct connecting the larger bladder with the stomach.
B, air-bladder of herring (Clupea harengus); b, pneumatic duct leading to stomach.
C, air-bladder of Corvina trispinosa, dorsal view.

We have seen how a typical fish swims, and we have only now to remember that

there exist many other fishes which move, as it seems, in quite a different way. The rays swim by flapping with their enormously enlarged pectorals, and the tail is but little used; the flat-fish move their whole bodies in several wave-like curves up and downwards; the pipe-fish progresses by means of an undulating motion of its long dorsal fin; and the sea-horse (Fig. 6) uses the same organ in a whirling, screw-like fashion. But these are more or less extreme cases of the elaboration of arrangements which, after all, are dependent upon the same general principle as those typical cases which have here been treated in detail.

FIG. 9.—COMMON PIKE *(ESOX LUCIUS)*.

This well-known fish may be styled the fresh-water shark. He frequently grows to large size, and is always characterised by great strength and ferocity. Many thousand disciples of Izaak Walton annually make war against him.

SOME PLANTS IN THE GARDEN OF THE SEA: A GROUP OF RED SEAWEEDS.

1, PLOCAMIUM COCCINEUM; 2, PTILOLA PLUMOSA; DELESSERIA SANGUINEA: 4, CORALLINA OFFICINALIS; 5, NITOPHYLLUM PUNCTATUM; 6, RHODYMENIA LACINIATA; 7, IRIDŒA EDULIS; 8, CALLITHAMNION CORYMBOSUM; 9, DELESSERIA RUSCIFOLIA.

BROWN SEA-WEEDS.

THE name "wrec," or sea-ware, has been from remote times applied to the marine sea-weeds when thrown on shore. Early charters made wrec the property of individual proprietors. Dr. Johnston tells us of one of 1228, which confirmed to the prior and convent of Durham certain rights. Among these was the right to gather, use, or sell "the wrec." In the opinion of some farmers a cartload of good ware or wrec is at any season of the year equal to a load of farm-yard manure, but at the barley-sowing time it is worth double; and ware-barley was at one time much esteemed by brewers. Some of the brown sea-weeds at last came to be distinguished as tangle and wrack. Of the latter, the following is a short account. One of the commonest species of sea-wrack is known as *Fucus vesiculosus*, the "brown bladder-wrack." The generic name, *Fucus*, was given it by the great botanist Linnæus; it is Latinised from the Greek φῦκος (*phukos*), which means a sea-weed, and certainly, so far as the whole north of Europe is concerned, there is no sea-weed more generally known. The second or specific name (*vesiculosus*) was also given to it by Linnæus, and has reference to the oval-shaped, bladder-like cavities or vesicles which are found here and there throughout the surface of the plants, filled with air. How often, as children, have we burst them! Commonly and widely diffused as this sea-weed is, it is within quite recent times only that we have learnt its whole life-history. The story of this life will serve in great measure for that of an entire section of the so-called olive-coloured algæ, and therefore we must treat of it a little in detail.

To clear the way before us somewhat, let it be understood that the whole structure of this, as of any other, sea-weed is built up of simple cells. Now a cell is a mass of semi-viscid or sometimes granular substance called *protoplasm*, which is mostly surrounded by a membrane called the *cell-wall*.* Countless numbers of these cells, more or less intimately united together, and *all* more or less assuming the same general form, constitute the leaf-like expansion known as the *thallus*, so that in proceeding to describe a fully-grown plant of the sea-wrack we shall be describing the various peculiarities assumed by its thallus. In most works on British sea-weeds this thallus is known under the name of *frond*, and by this name we shall—on account of its familiarity—continue to designate it.

Let us now imagine that we have a frond of *Fucus vesiculosus* before us (Fig. 1). If living near a rocky part of our sea-coast, nothing is easier than to obtain specimens; and even if inland, this sea-weed is so commonly used to pack lobsters, crabs, and oysters with, that no doubt morsels of it can easily be procured. If the specimen has been taken carefully off the rock on which it grew—not simply cut off—the part by which it was attached to the rock will be found to be somewhat disc-shaped. The cells have here grown out into a flattened or slightly elevated mass, closely adherent, which serves the purpose of fixing the whole frond firmly to the rock on which it from the first grew. In reality it only serves as an anchor, and does not, as in flowering plants, play any part in the nutrition of the sea-weed, so

* The reader is referred to the paper on "Yeast," CASSELL'S POPULAR SCIENCE, Vol. I., p. 420, for a fuller description of a cell.

that in this respect it has no affinity with a true root. From this disc the frond arises. The appearance and shape of this will vary immensely both in size and outline. Specimens may be met with near high-water mark, and in muddy

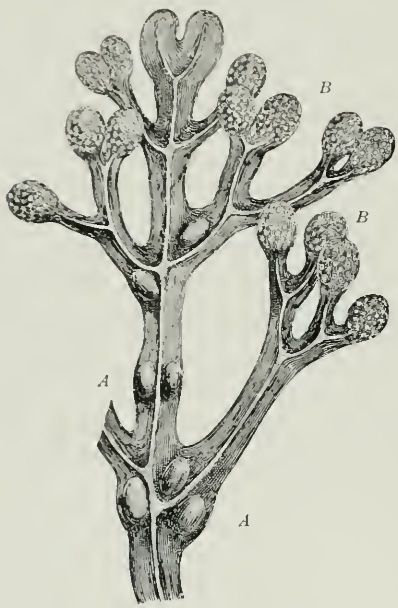


FIG. 1.—A FROND OF A COMMON BROWN SEA-WEED, THE BLADDER WRACK OR WREC (*FUCUS VESICULOSUS*).

A, air-bladders which help to give buoyancy to the fronds; B, " conceptacles."

ground, not more than an inch in length; while others growing near low-water mark, and on the sheltered side of some pier, may be found with fronds of upwards of three feet in length. The fronds will also vary quite as much in width. They are flat, and are leather-like to the touch. They soon become branched, these branches being at first two in number, and each of these branching into two again.

This method of branching is spoken of by the botanist as *dichotomous*. The growing point of the thallus consists of a group of actively growing and dividing cells, and it is this group of cells from which the branches of the thallus spring. The latter may be forked several times, but in all cases the branches will be found to lie in the same plane as each other.

But while this branching forms thus a series of twos, the branches are not always equal in size. The edges of the frond and its branches are even, like the edges of a hyacinth leaf, and along the central portion of both there runs a thicker cord-like portion called the mid-rib. Here and there, but chiefly in the upper portions of the branches, inflated bodies will be seen, mostly in pairs, and to the left and right of the mid-rib. If these, while still fresh, are pressed between the finger and thumb, they will be found to be highly elastic; and if much pressure is used, they will burst. These are the air-bladders, which, from their very constant presence, give the name to the species. In size, they vary in proportion to the diameter of the frond. The substance of the frond is tough, and, while it will tear into strips, it cannot easily be broken across. Its colour is of a dark olive brown, which is of a lighter hue in young specimens.

So far the appearance of this frond can be seen by the unassisted vision; but if we wish for a more intimate knowledge of its structure we must make a section through—let us say—the whole frond, right across the centre of one of the air-bladders. If we now take a very thin slice (Fig. 2) from this section—one so thin that the light will have no difficulty in penetrating it—and examine the same with a low power of the microscope, it will be found that the whole is formed of a system of cells, and that although these are all referable to one type, yet that here and there they present somewhat different forms, and that their walls are of somewhat different consistencies. The outer portion will contain a series of cells one or two layers deep, with thickened walls, and the outer walls of the outer layer will show a thin, skin-like pellicle. This series we may call the

rind layer. It is this we come into contact with if we pull the frond through our fingers, and it is this which gives to the touch the sliminess when the frond is quite fresh. Within this layer other cells of the same nature, but with less dense cell-walls, are to be seen. Then we come to the large empty spaces caused by the rapid growth of the surrounding cells, and which form the vesicles or air-bladders; between these the mid-rib is found to contain cells of a peculiar shape—longer than broad—running in many rows, mostly parallel to one another, but sometimes interlacing with one another, thus giving to the frond its well-known rigidity. These last-mentioned cells are better seen, and their shape is easier to be understood, if the section be made not transverse to the axis of the frond, but vertically; then they will be seen to run like threads through the centre of the frond, and to be surrounded by the two outer layers of cells above alluded to. The reddish-brown colouring matter (*phycophæin*) conceals, as it were, the leaf-green colouring matter (*chlorophyll*), which, however, is always present, and in very young specimens may even be seen.

So far we have been considering the barren frond; but this sea-wrack develops organs, the functions of which can be compared to those of the stamens and pistils on a flowering plant. These algæ fronds, when fertile, are either male or female; and their organs of fructification present much of interest. They are to be found crowded around the summit of some of the branches (Fig. 1), and consist of little spherical cavities plunged, as it were, in the rind layer of these portions of the frond. These cavities are known as *conceptacles*, and in our plant these conceptacles on the same frond are either all male or all female. In both cases the cavities will open out by means of a pore (*ostiole*), from which the reproductive bodies will ultimately escape. From July to the end of May, all along our southern shores, these conceptacles will be found more or less developed on most of the adult fronds. If we cut through a male conceptacle, and examine it in the same way that we did the slice through the frond (Fig. 2), we find the hollow portion filled with a forest of delicate filaments, growing outwards from the cells forming the floor and side walls of the cavity. These filaments are composed of cells, which elongate by a form of cell growth called "apical cell growth," and give rise to numerous side cells, which often grow into branch filaments after a like fashion. The cells composing these filaments, thus enclosed within the male "conceptacle," are of two sorts. In the first the protoplasm either adds to the filament, or, as in the second, divides itself into an immense number of particles, which are each furnished with two curious whip-like bodies (*cilia*). These particles burst out through the cell wall, and by means of their vibrating *cilia* move rapidly about. Multitudes of them escape together, and most of them make their way to the common pore or opening above referred to—these are the male organisms (Fig. 3). These functionally are like the pollen bodies in the flowering plants; they can no more grow up into little plants of sea-wrack than the pollen bodies of a cactus flower could give of itself origin to cactus plants. What is their fate?

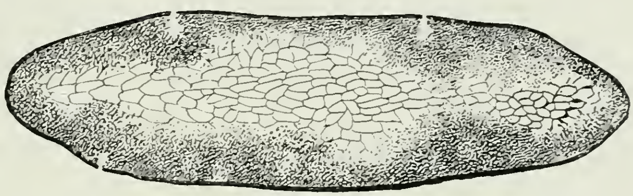


FIG. 2.—CROSS SECTION OF FROND OF THE BLADDER WRACK.

We shall see in a moment; but we must first describe the female conceptacle (Figs. 4, 5 and 6).

In their general shape and appearance these are very like the male conceptacles, but on an examination of their contents we find the forest-like mass of filaments somewhat less branched—more like rigid, jointed hairs—and the cells with the dividing protoplasm are now of proportionally much larger size. Besides, these cells never give origin to more than eight daughter cells, whereas the corresponding ones in the male conceptacles give origin to quite a swarm, and the daughter cells also are not furnished with locomotive cilia. When these female organisms are expelled out of the pore in the female conceptacle, partly guided thereto by the long, hair-like filaments, they fall into the salt water; and, if the reader has followed the description so far, he will remember that at this moment they are nothing but little globe-like bodies of soft protoplasm, which by themselves would soon die. But if in their first entrance into an independent life they meet with any—even one—of the bee-like swarm of male organisms which are rapidly flying about by means of their whip-lash like bodies, these at once impinge upon them, and the two functionally distinct masses of protoplasm mingle their substances—the larger mass is fertilised by the smaller, and the product of the fertilisation subsiding on, or being borne to, the nearest rock, will soon be surrounded by a cell-wall. Next this cell will divide into two portions: one, the lower, will attach itself to the rock, giving rise in time to the disc-like attachment already described; the other, the upper, will grow up in time into the mid-rib part of the future thallus, giving off the flat, wing-like portions as it grows. Thus, we here come back to the stage of our plant-life from which we started, and we can understand that, however complicated its structure was as we tried to examine it in its full-grown form, we traced that life back until we found it start out of two differently sized and functionally distinct masses of protoplasm; and these, too, alike in this—that they at one time formed part of the very protoplasm of the plant itself, but were eventually set free, so as to carry on the life, not of the individual plant, but of the species of plant to which that individual belonged. This form of reproduction of the species may be called true reproduction (*sexual*).

In this group *Phæophyceæ* the three series *Phæosporeæ*, *Dictyotaceæ*, and *Fucaceæ* are placed by many botanists; others keep the three series distinct. Included in the *Fucaceæ* are some of the commonest of all sea-weeds of northern oceans, in addition to *Fucus vesiculosus*, already dealt with.

Belonging to the same genus as the species above described is the serrated sea-wrack (*Fucus serratus*), also very common, and easily distinguished from the former by the absence of air-cavities and by the deep toothing or serrations of the edges of the fronds; also the conceptacles arise more on the flat surface of the tips of the fronds than in terminal tufts, as in the bladder-wrack. This species, too, is confined to the Atlantic coasts of Europe, and does not, like *F. vesiculosus*, extend to the Pacific nor into the Mediterranean Sea. The other two British species of this genus are more rarely to be met with. In *F. ceratoides* there is a resemblance to *F. vesiculosus*, but the absence of the air-bladders will at once distinguish between these two, while the edge of the frond being smooth will distinguish between it and *F. serratus*. It frequents land-locked bays and estuaries, and seems to like a little admixture of river water with that of the sea. The tufts of conceptacles arise in masses from the

lateral branches of the fronds, which are about half the width of the barren branches. The male and female cells are

FIG. 3.—MALE ORGANS OF BLADDER-WRACK.

The "antherozoids," as they are technically called, are borne upon the arms of a branching hair. Some of the nimble little bodies may be observed escaping on the left.

to be found on different plants in these species. In *F. Mackaii* the fronds are peculiar, being cylindrical, and not, like those of all the other species, flat, and they grow in globular masses or tufts about the size of a human head, which seem not to be attached to rocks or stones, but to anchor themselves among the mud or loose stones. The mass of conceptacle-bearing cavities form grape-like bunches which hang from the ends of some of the lateral branches. This species, which is found on the west coast of Ireland and in Scotland, would well repay a thorough examination. Another pretty common species is known as the knotted sea-wrack (*Ascophyllum nodosum*). This is put into a genus separate from the others, for the reason that there are, as a rule, never more than four daughter-cells formed in each spore-producing cell of the female conceptacles, whilst in those of *Fucus* there are eight such daughter-cells. The root-like portions of this species are often two inches in diameter; the fronds will sometimes grow to a length of five or six feet; the air-bladders will be one to two inches long; and the edge of the frond is toothed, but the serrations are far between. From the axils of some of these spring the pear-shaped masses of conceptacle cavities—bright yellow when the spore masses are ripe. This species is common on the Atlantic shores of Europe and America, and used to be largely burnt for the manufacture of kelp. Another interesting species, called *Pelvetia canaliculata*, is often to be seen growing so far removed from low-water mark as to be only within reach of the spray. Under such circumstances the little tufts look very unlike a fucoid. It never seems to care to venture itself lower down than to be within the reach of half tide. Thus it happens that on hot summer days the fronds may be found apparently quite dried up and withered, and yet, on the return of the

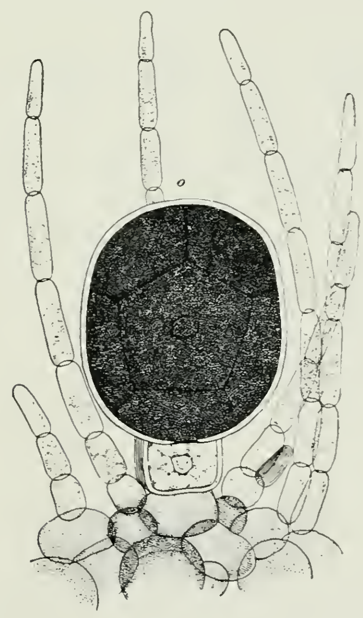


FIG. 4.—THE FEMALE ORGAN OF THE BLADDER-WRACK.

The "oogonium" (o), as this large cell is called, now proceeds to divide into eight parts. See also Fig. 5.

tide, or even by the splashing up of the salt spray, these soon lift up their heads and recover all their former freshness. Both sexes are to be found in the same conceptacles. In *Bifurcaria tuberculata* the root-like portion is composed of branching fibres. The attaching disc is thick, composed of round, goose-quill-like branches. Like the last-mentioned species, it is hermaphrodite.

In the genus *Cystoseira*, of which there are five British species, the fronds assume a bush-like form. There is a thickish stem—perennial—with more or less numerous branches; the air-bladders are often arranged in rows, whence the name (*kustis*, a bladder, and *seira*, a chain). The largest and finest species is *C. fibrosa*, and one of the most beautiful is *C. ericoides*. Both are pretty common, as is also *C. granulata*. *C. discors* is not so plentiful, and the fifth species, *C. barbata*, is probably not a native. In the sea-thong (*Himanthalia lorea*), the portions of the frond which bear the conceptacle cavities are of annual growth, and the perennial vegetative portions are reduced to the little cup-like bodies well known to collectors. The male and female conceptacles are on different fronds, and the female mother-cells only give origin to one daughter-cell—not to four, as represented in Professor Harvey's pretty plate.* In all these forms of fucoids it will be noticed that the air-bladders, when present, are found immersed in the frond. But we must very briefly call attention to two genera included in the native flora, in which these are stalked, thus standing out like little floats. The first of these, scarcely admitted by some into our flora, is the genus Sargassum, to which the gulf-weed (*S. bacciferum*) belongs. Its generic name is said to be derived from the Spanish *sargazo*, the name given to it by the early navigators. Its air-bladders being like berries justifies its specific name. A true native, and the last species to be noticed, is the sea-oak (*Halidrys siliquosa*), a very handsome and not uncommon form. The air-bladders are not only stalked, but arranged in transverse partitions looking like pods, or the inflated fruit of the radish.

We have thus enumerated all the native species. This group of the sea-wracks, however, by no means contains all the algæ with a brown colouring matter in their cells. On the contrary, the group stands out as one quite singular in this, that it has but the one form of reproduction above described. Another form must be very shortly noticed. Sometimes the contents of a cell or cells break up into a large number of cilia-bearing masses of protoplasm, not unlike the male particles (*antherozoids*) already described, but differing from them enormously in function, inasmuch as each one of them can grow up into a perfect frond. These tiny spores, thus endowed, not only with life, but with a power of living and developing unaided, are well called *zoospores*. There are no zoospores in the fucoids, but they are to be found in the great sea-tangles (*Laminaria*), and in the wonderfully common *Ectocarpi*, known to every sea-weed collector as a genus of filmy, silky brown sea-weeds, to be found in every rock-pool, and often growing in tangled masses from the fronds of the sea-wracks. In another section of brown weeds, which includes the very lovely peacock-tail algæ (*Padina pavonia*), only to be found very rarely on British shores, and the common *Dictyota dichotoma*, these zoospores have lost their power of locomotion, and, being developed in fours in the mother-cells, are called tetraspores (four spores). There are thus three sections of the brown sea-weeds:—1, without zoospores (*Azoosporeæ*)—the life history of this section we have studied as above; 2, with zoospores (*Zoosporeæ*); and 3, with tetraspores

* "Phycologia Britannica," Vol. I., Plate IV.

(*Tetrasporeæ*). The life history of these last is full of interest.

The fucoids are widely distributed throughout the cool waters of all the

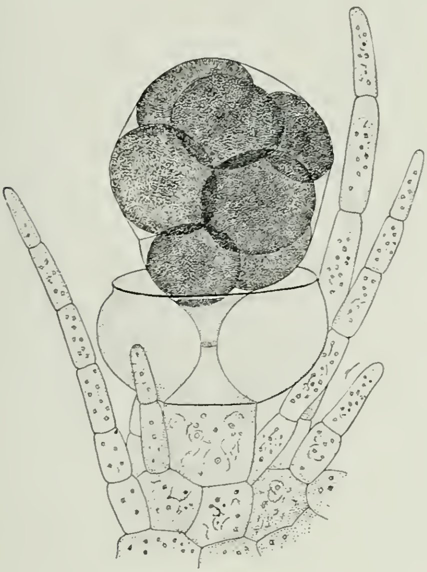


FIG. 5.—SHOWING THE EIGHT *OOSPORES* OR EGG-SPORES.

The wall of the "oogonium" is here removed in order to show this division.

oceans, diminishing sensibly in the warm semi-tropical or tropical parts. Around our own shores, wherever these are rocky, they like being alternately exposed to the atmosphere and covered by the sea; they thus form a most characteristic feature when the tide is out. From the toughness of their fronds, very few of the group of the fucoids will adhere to paper when drying, and from this peculiarity and their comparatively large size they are not favourites with collectors, by whom they are accordingly not stored up like their beautiful green and red allies (*see* Coloured Plate). They have, nevertheless, a deeply interesting history of their own, and from an economic point of view they are worth all the others put together, for they supply manure to the farmer.

Before the method of obtaining carbonate of soda from common salt was discovered, "kelp," which is obtained by burning some of these brown sea-weeds, was the common source of supply. The sea-weed was first dried in the sun, and then slowly reduced to ashes by fire in shallow excavations. Chloride of sodium, carbonate of soda, sulphate of soda, sulphate of potash, and iodide of potassium, together with some insoluble salts and colouring matter, are all to be found in "kelp." It has been estimated that a ton of kelp will give about 8 lb. of iodine, 3 to 4 gallons of naphtha, and a quantity of sulphate of ammonia, varying from 1½ to 4 cwt. At the beginning of the last century about 20,000 tons of kelp, representing a money value of £200,000 to £300,000, were made on the west coast of Scotland alone. Now the entire pro-

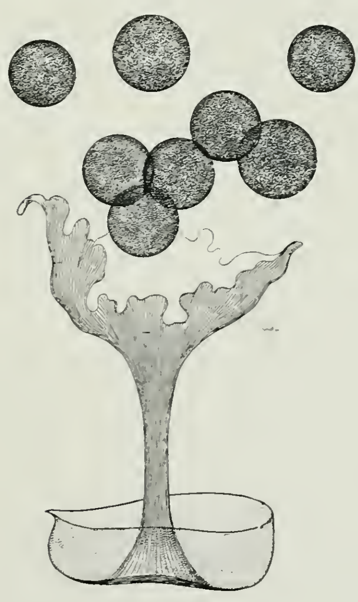


FIG. 6.—THE EGG-SPORES ESCAPE.

Finally the wall of the oogonium ruptures and the egg-spores escape into the wide waste of waters, many to be lost, a few to be fertilised by the free-swimming antherozoids, and thus to set up young seaweeds.

duction of the British Isles is much below this figure. In Orkney, Shetland, and on parts of the coasts of Ireland, the industry still exists, although it cannot be said to flourish.

LODGERS AND BOARDERS IN LOWER LIFE.

By Dr. ANDREW WILSON, F.R.S.E., etc.

THE character of the "parasite" is one which from classic times has been deservedly held up to ridicule and scorn by the universal consent of humanity. The cringing, dependent, and fawning servitor, dancing attendance on the heels of a usually tyrannical patron, constitutes a picture in favour of which no one may feel prepossessed; and the general idea of such a relationship is that of a contemptible alliance betwixt master and servitor, calculated to effect no good work upon their human surroundings. The term "parasite," as applied in lower life, whilst it possesses certain analogies with the human state so called, nevertheless, exhibits a widely different aspect when its entire features are taken into consideration. The animal parasite, in the majority of cases, is unquestionably, like its human representative, a degraded creature. It will be found most frequently to have lost whatever independence it once possessed, and to have merged its existence in a slavish dependence on its host. In not a few cases this dependence will be found to have proceeded so far that the parasite has become stomachless and mouthless, and feeds itself, as best it may, on the fluids which its host elaborates for personal use. Thorough degradation may thus be said to follow the adoption of a parasitic life in cases where such an existence is best typified in the animal world. But here the comparison of the human and animal dependent may be lawfully said to end; and at this stage the differences begin, on the other hand, to be plainly apparent. The parasite in higher life is at the beck and call of his master, and is bound to respond to every whim and caprice of his owner. Not so the parasite in lower life, which exists usually as a source of irritation, and often as a cause of disease, to its uninviting, and it may be unconscious, host. The human dependent may, it is true, exist for his own ends, and may ultimately benefit himself through his despicable ways and the petty meannesses of his life. But such advantage may be said to be the invariable rule of the parasite in lower life. The latter not only lodges, but may board, at the expense of its host. It obtains lodgment and food in the easiest fashion and in the cheapest manner. It is a persistent "bad lodger," which not only pays no rent, but may in the course of its existence benefit itself by the physical ruin of its benefactor. Sindbad's "Old Man of the Sea" was not a more persistent tenant on that hero's shoulders than are most parasites on or within the bodies of their hosts. And, unfortunately, the latter may hardly be shaken off as was Sindbad's ancient burden; inasmuch as, when parasitism has become the way of life of a living organism, the law that "habit" becomes "a second nature" receives a new illustration, and the parasitic existence, once begun, tends to become the perpetual and normal life of the dependent being.

Let us endeavour, in the next place, to gain some idea of the structure and development of certain typical parasites, and thereafter seek briefly to discuss the probable origin and laws of parasitic life at large. In such a zoological ramble we may light upon facts which may not only "feed the curious" within us, but serve

HERMIT CRABS FIGHTING.

THE HERMIT CRAB IS NOT SO WELL PROVIDED BY NATURE WITH THE MEANS OF DEFENCE AS HIS RELATIVES, SO HE SEEKS AN ABANDONED UNIVALVE SHELL, AND MAKES IT HIS HOUSE AND HIS CASTLE, WHERE, WITH THE AID OF HIS VERY SERVICEABLE CLAWS, HE CAN DEFY INTRUDERS. HE IS RATHER AN ILL-TEMPERED FELLOW, AND PUGNACIOUS TO A DEGREE.

the higher mission of intellectual nurture, in providing food for thought and wise reflection.

Some simple cases of parasitism may first engage our attention, since these less complicated relations betwixt animals may serve perchance to show how the more complex associations have been acquired. Many cases are known to naturalists in which one animal attaches itself to, or merely associates itself with, another animal of widely different kind. Such association is not only of constant and invariable occurrence, but is, moreover, inexplicable, save perhaps on the idea of a chance companionship, which under the influence of habit had become a sworn friendship. No better example of such association could be found than that of a species of sea-anemone (*Adamsia palliata*), which attaches itself to the shells in which hermit-crabs (*Pagurus Prideauxii*) ensconce themselves after the manner of their kind (Figs. 1 and 2). Invariably we find crab and anemone dwelling together, the former toiling along, house on his back; and his anemone friend, securely posed on the house in turn, is carried about much as the accompanying illustration (Fig. 2) depicts a colony of tube-worms borne on the shell in which the crab resides. Between these "messmates," as they may be termed, the best of understandings appears to exist. Constant association, perpetuated from generation to generation, has perfected relations of a friendly character between crab and anemone. The crab has been seen to feed the anemone by aid of his long nippers, and to remove the anemone to a new and larger shell when, through his physical increase, a change of quarters was demanded. The beginning of parasitism is thus illustrated, as also is the case of mutual benefit arising from the association of the different forms. The sea-anemones benefit by their being fed, while the crabs are protected from the attacks of fish enemies by the presence of their companions on their shells.

FIG. I.—THE HERMIT-CRAB (*PAGURUS PRIDEAUXII*) IS A WALKING CONSERVATORY.

His amateur status is not good, however, for he cultivates sea-weeds with a view to profit; they enable him to conceal his claws and assume an innocent appearance when he lures his prey to destruction.

Of a more intimate kind, and more nearly approaching parasitism itself, is the relationship known to exist between such

animals as sea-anemones and some fishes, and between such molluscs as mussels and certain small crustaceans named "pea-crabs" (Fig. 3). Any visitor to the seaside who has touched the outspread tentacles of a sea-anemone knows full well how quickly the animal retracts the feelers, and contracts its entire frame. The object of such sensitiveness is not far to seek. Since the prey of the anemone —consisting of crabs, whelks, and all unwary creatures which may stumble across its tentacles —is captured by the tentacles, and primarily through the warning which the property of sensation gives to the feelers of the animal, it would be therefore a perfectly just assertion to say that a sea-anemone is a highly sensitive animal, and that objects touching its tentacles are readily and quickly seized and engulfed within its sac-like body. But what may be said of the relationship between certain tropical sea-anemones of large size and some small fishes, whose habitual dwelling-place appears to be the interior of the anemones' bodies, and which swim in and out of the mouths of their hosts at will? Nor is the case any the less surprising when we find it asserted on good authority that the anemone may contract its body, enclosing the fish, and, thereafter expanding itself, allow its "messmate" to swim freely about, only to return again, however, to its strange but habitual dwelling-place. Considering the rapacity of ordinary anemone character as illustrated by the seizure of food, how may the immunity of a fish which has ventured not merely into the lion's "jaws," but into its very stomach, be accounted for? Once again we are forced to fall back upon the idea of "habit, use, and wont" as inducing such a harmonious relationship. It might be suggested that the fish may benefit from the easy terms on which it may obtain food within the stomach-sac of the anemone. If this view be correct, then the case may truly be described as that of two "messmates"; but the details appear as strange and curious after this suggestion as before. Such a case may show how parasitic habits might be inaugurated in the case of an animal more likely to become wholly dependent on a host than the fish, since the partial dependence of a likely animal on the anemone might be replaced by a fuller and more complete life of ease and indulgence.

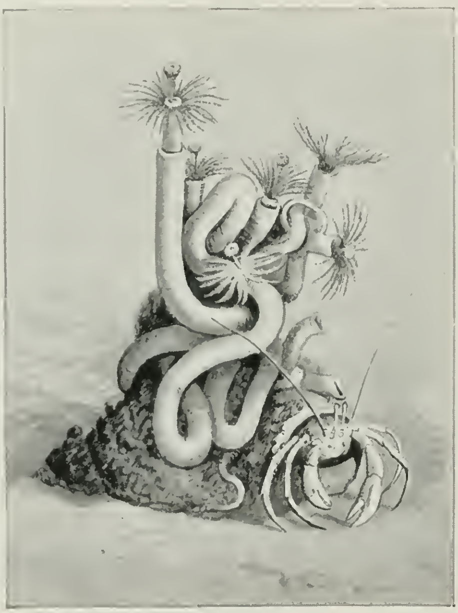


FIG. 2.—HERMIT-CRAB AND TUBE-WORMS.

Somewhat resembling the preceding case is that of the "pea-crabs" (Fig. 3), those minute crustaceans which occur not merely within the shells and bodies of mussels, but are also found as lodgers within the breathing chambers of the "sea-squirts" or Ascidians (Figs. 4 and 5). How or why these crustacean intruders are tolerated amongst the sensitive tissues of their hosts is another mystery, inexplicable as to its origin, and equally mysterious in its continuance, save on

the supposition that custom has habituated the mollusc or sea-squirt to the presence of its guests. Pliny of old, indeed, credited the pea-crab with the function of pinching its landlord by way of warning him against the inroads of other and perchance less welcome intruders; but the suggestion does more credit to the classic naturalist's ingenuity than to his knowledge of animal psychology and relationships. That the pea-crabs are most probably "lodgers" only, and not boarders, within the sea-squirts at least, seems a likely idea, from the writer's own observations of the habits of these crustaceans. Pea-crabs may be seen to emerge at night from sea-squirts kept in an aquarium, to feed on the floor of the vessel or tank, the crabs retreating to their shelter, on being alarmed, with a rapidity which speaks volumes at once for their familiarity with their place of refuge and for sea-squirt tolerance with lively lodgers.

FIG. 3. — PEA-CRAB.

In these cases a habit of association has clearly been contracted, with the result of invariably inducing the stated companionship of two animal forms, widely separated from each other in point of structure and rank in the zoological category.

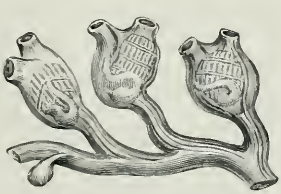


FIG. 4. — SOCIAL ASCIDIAN (*A. PEDUNCULATA*).

We may now proceed to note the details of some cases in which this association has developed into a still closer intimacy, and in which the limits and territory of true parasitism may be said to be attained.

Amongst the parasites that infest the human territory and that of higher animals at large the tapeworms are perhaps the best known examples. These organisms inhabit, as their special sphere, the intestines of man and other warm-blooded animals—namely, quadrupeds and birds. They may attain a length of many feet; and when scientifically examined each tapeworm is seen to consist of, firstly, a very minute "head," armed with hooklets and suckers for adhesion to the intestine; secondly, of a slender portion composed of imperfectly formed joints, the so-called "neck"; and, thirdly, of numerous flattened "joints," of oblong shape. It must be first noticed that the "joints" do not correspond to the joints or segments of an ordinary worm. In the tapeworm, indeed, each joint is really a semi-independent animal; and the whole worm, instead of being a single organism, is thus in reality a collection or colony of beings. The "head" is the most personal part, so to speak, of this compound organism, since the joints are produced from the head and neck by a veritable process of "budding." Each fresh joint appears to be produced

FIG. 5.—SIMPLE ASCIDIAN (*A. MICROCOSMUS*).

between the head and the already formed segments. As this process of growth may be said to proceed continuously during the lifetime of the organism, we may readily enough understand how tapeworms may attain the length and dimensions they frequently exhibit.

The tapeworms have little to boast of in the way of structure or organisation. The head contains the main masses of the nervous system, which send two nervous filaments backwards through the joints, and two main tubes or "water-vessels" run down one each side of the body. Each "joint" may be described as simply a receptacle for the development and production of eggs. In each joint we see the greatly branched "ovary" or egg-producing structure, within which thousands of eggs—destined, under favourable circumstances, to produce as many tapeworms—are developed. Thus we clearly appreciate the almost unlimited fertility of these animals when we discover that the organism consists of many segments, each capable of producing its thousands of eggs; whilst each egg that undergoes full development is invested with the power of giving origin in turn to a tapeworm organism composed, as before, of its hundreds of joints.

"What is the life history of such an organism?" is a query which may best be answered through a study of its development. Liberated from the body of their host, the joints of the tapeworm, through their decay, disperse their minute eggs abroad. The eggs, to undergo development into tapeworms, require, however, to pass the first part of their existence in a different animal from that in which they are to reside as mature tapeworms—that is to say, the egg of the common tapeworm (*Tænia Solium*), which inhabits the human digestive system, would come to nothing were it to be swallowed by man. For its due development it requires to be first swallowed by a warm-blooded animal as a first host—the animal in question being a pig. Swallowed by the pig, the egg of the tapeworm soon liberates from its covering a little "embryo" provided with six hooklets. This young tapeworm shows no disposition to develop the characteristic form of its parent within the pig, but at once proceeds to bore its way through the walls of the animal's stomach, and to take up its abode usually in the pig's muscles, or it may be in the liver, brain, or some other organ. Here it becomes a "resting larva." It develops around its body a sac or bag containing fluid, and is now known as the *scolex*. Already we may perceive a minute head and neck, but no further traces of the mature tapeworm are to be seen. Here, also, it can attain to no further development. Its career within its pig host ends thus; and if the pig should die a natural death and be buried, the "resting young" of the tapeworm would share the fate of disintegration, destruction, and decay which would in the latter event await the tissues of the pig. Let us imagine, however, that, instead of the unlooked-for and unusual contingency above noted, the pig's muscles are in due season converted into pork, and that man partakes of that commodity, especially in an uncooked or imperfectly prepared condition. Then each "resting tapeworm" within its sac receives a fresh start in life, and enters upon the concluding phases of development. For when swallowed by man the little sac is dissolved. By means of its hooklets, the resting larva attaches itself to the lining membrane of the digestive system. Next ensues a process of budding. Joint after joint is duly produced, and the form of the mature tapeworm, with its eggs ready for development, as we at first beheld it, again appears in the round or cycle of development.

Such is the curious story of the development of these parasites. The main

features of that biography consist in the remembrance of the facts that these animals possess two hosts, and that they do not attain full development in the animal which first harbours them. Thus, from the resting larvæ in underdone pork man derives the common tapeworm. From underdone beef he may obtain another kind of tapeworm, the first stages of whose existence are thus spent within the economy of the ox. The young of the tapeworm commonly found in the dog and fox inhabit the liver of the rabbit; another parasite of the dog being obtained from the brain of the sheep. The cat obtains its parasite in the most natural fashion from the liver of the mouse or rat. And man, in turn, may act as a first host when he harbours in his liver the dreaded "hydatids," which are simply the immature young, or resting forms, of a tapeworm attaining maturity in the dog. No more curious life history than that of a species of tapeworm (*Tænia cucumerina*) can well be imagined; this parasite inhabiting the dog's digestive system. The resting young of this tapeworm inhabit the body of the dog-louse—which is duly swallowed by the dog in the act of cleaning his coat—and there becomes the full-grown tapeworm. The eggs of this mature parasite are in turn swallowed by the dog-lice, and become the resting young which are destined to repeat the history through which their progenitors have passed. Here there is seen parasitism within parasitism; and, to say the least, it would be a puzzling task to account for the origin of the somewhat complex relationship which has thus been developed betwixt the louse, the tapeworm, and the canine host which protects the one and gives shelter to the other.

Equally interesting, and in some respects similar to the development of the tapeworms, is the history of the flukes (Fig. 6). Everyone has heard of these flat-bodied "worms"—each comparable to a single joint of a tapeworm—which inhabit the bile ducts and liver tubes of the sheep, and produce those symptoms of emaciation and disease in that animal collectively known as the "rot." The eggs of the fluke escape into water, and give birth to young, or embryos (Fig. 6, B), which at first swim freely about. Soon the young fluke loses its locomotive powers, becomes a tadpole-like being, and enters the body of a fresh-water snail. There it remains quiescent, but undergoes changes which bring it nearer the condition of fluke. When the snail is swallowed by the sheep in the act of drinking—or it may be when the young flukes escape from the snail into water and thus gain ready access to the sheep's economy—the final stage in development is duly brought about, and the young flukes, making their way to the liver of the animal, become perfect and mature beings. Thus we see that, as in the tapeworms so in the flukes, two hosts are required for the due development of these parasites; and it may not be amiss to remark in passing upon the fortunate nature—in so far as the higher animals or final hosts are concerned—of this arrangement. But for the thousand and one chances of destruction which await the eggs of these parasites, and for the chances which tell against their successful lodgment in their first hosts, and also against their successfully overcoming the difficulties of their complicated development, man's estate would be simply overrun with these organisms, and higher animal life at large might well fear rapid extermination.

Instructive and interesting also is the account of the development of the notorious *Trichina*, which is capable of causing grave symptoms or death by its attack. This parasite is a minute, thread-like worm, which as it exists in the *muscles* of man, of the pig, or other animals, is

immature and harmless. When the flesh of the pig, for example, containing these trichinæ—which lie coiled up each within a little "cyst" or bag—is eaten by man, a wondrous activity is exchanged for their previously inert condition. These parasites, set free within the human stomach, rapidly produce their young by thousands. These young are debarred by the laws of their development from attaining any further advance in life before passing a term of pupilage, so to speak, in the

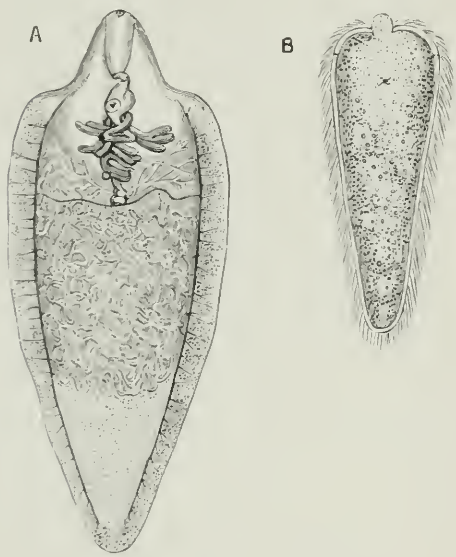


FIG. 6.—DEVELOPMENT OF LIVER FLUKE.
A, sexually mature (after Blanchard). B, embryo (after Leuckart).

muscles. Hence arises the danger of trichina-visitation; and then comes the tug of war. For the rising generation of these parasites, produced in the stomach, now bore their way through the tissues to a resting place in the muscles, and in the act of migrating cause pains and illness, often of a serious character. Once settled down in the muscles, all danger, however, is past. For each worm develops around itself a sac or bag, wherein it lies ensconced until swallowed by another warm-blooded animal—an utterly unlikely fate in the case of man's muscles, the parasites of which will simply undergo degeneration, and be ultimately converted into so many specks of lime.

What are the lessons which a subject that at first sight might be deemed of an unsavoury kind seems well calculated to teach us concerning parasitism and its origin? Briefly summed up, we may say that, firstly, parasitic habits are certainly not of original nature, but have been acquired—in other words, the parasite was not always attached and helpless, but was once free and dissociated, and acquired its dependent habits in consequence of some alteration in its way of life which benefited its race. "How may such a statement be supported?" is a natural inquiry. I reply, by the consideration of the various graduated stages and modifications in parasitism, and by the life-history of parasites at large. We may trace every stage in the parasitic dependence, and in the degree of intimacy which exists betwixt hosts and lodgers. From the simple condition of mere lodgment and attachment (as in the case of the anemone and hermit-crab), to that of "messmates," or pure "lodgers," is an easy transition. The fishes living within the anemones, and the pea-crabs within mussels and sea-squirts, exemplify cases of the latter description. In these instances there is an association more intimate than that existing between the anemone and crab; and although there is an independence of host and lodger, there are to be traced, nevertheless, the beginnings of truly parasitic habits. The tapeworms and their allies, as true parasites, illustrate beings which have undergone great modification of their parts and organs, and which, having gradually accommodated themselves to their surroundings, have become lodgers and boarders, feeding themselves at the expense of their hosts.

But we gain still clearer ideas of the originally free and non-parasitic state of animal lodgers and boarders if we con-

sider the meaning of the free stages witnessed in their development. No better illustration in support of this latter idea, that their development affords a clue to the whole history of parasites, could be cited than that of *Sacculina* (Fig. 7)—a low form of crustacean, and a kind of poor relation of crabs, shrimps, and their allies. The *Sacculina* exists as a bag-like growth on the bodies of crabs. It may be described as a bag of eggs and nothing more, attaching itself by root-like processes to its host, from whose tissues it absorbs its nourishment. From its structure as an adult *Sacculina*, indeed, we could not guess its true nature, seeing that it possesses few or none of the ordinary belongings of the animal creation. But if we watch the development of one of the many eggs this bag-like being contains, we may then hazard a guess as to its nature and concerning the history of its past. Each *Sacculina* egg gives birth to an active little creature, named a *Nauplius* (Fig. 7, A). This little being possesses three pairs of legs or feet, an oval body, and a single or cyclopean eye. Soon the body becomes enclosed in a "shell"; the front pair of limbs increases at the expense of the others, which are cast off; whilst six pairs of swimming feet are developed in their place. Ultimately, these little creatures attach themselves to their crab hosts, the limbs drop off, the two front limbs remain developed, and become altered to form organs of adhesion to their hosts, and the body itself finally assumes the form of the sausage-shaped organism we see in the adult *Sacculina* (Fig. 7, B).

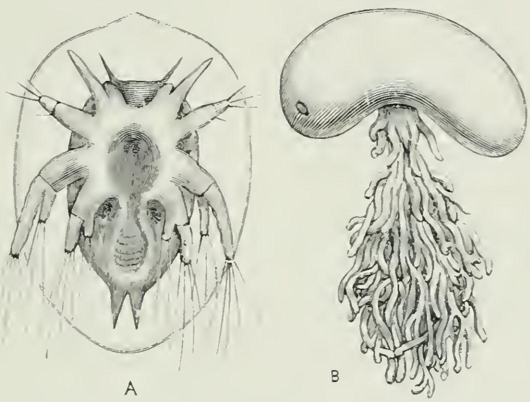


FIG. 7.—DEVELOPMENT OF *SACCULINA*.
(After Haeckel.)
A, larva; B, mature animal.

Thus, if "development" may be trusted as a criterion of the history of the *Sacculina* race, we may believe that at first these parasites were represented by free-swimming beings resembling the *Nauplius* (Fig 7, A), which now appears as the first stage in their lives. It may with equal justice be assumed, from the facts which nature reveals to us, that the fixed and rooted *Sacculina* is itself a later product of development, and appears as the result of altered habits and of a changed way of life on the part of the original race. Such conclusions, though merely hypothetical, are not unsupported by the history of other animal forms. On the contrary, change and variation may be regarded as representing factors and means of normal kind in inducing alterations in the structure and habits of living beings. No one may doubt the existence and operation in the world of life of laws which direct animal and plant forms along the "grooves of change." Our difficulty lies, not in determining the existence of these laws, but in reaching the "law within the law," on which the degree and succession of changes depend. Such ideas that alteration and variation are natural actions of life are the result of that wider study of living beings which has of late years been prosecuted.

Of old, the "fixity" of species and the

permanency of animal and plant forms was esteemed an axiom of biology. Now we hold that the production of varieties and races is one of nature's statutory procedures, so to speak. We do not yet know, it is true, the limits of variation in different animals or plants, but experience shows us that these limits probably vary greatly in different species. The causes of variation are likewise still undecided, but amongst these causes we may rank the influence of surroundings and of changed environments as of the highest importance. One of many theoretical conclusions to which the subject of parasites may, therefore, lead is that alteration and modification of the lives and structure of animals appear to be normal occurrences in nature. Under the influence of new ways of life and of changed conditions, animals once free have become attached as parasites, and, from the possession of definite structure and organisation, have become degraded, and have degenerated to the existing state of many parasitical forms. Change and modification are thus seen to be important features in ruling the destinies of living beings, either raising them in the scale or lowering and degrading them. No better example of the latter fact may be cited than that illustrating the manner in which the so-called "vicious circle" of parasite life is perpetually maintained.

Photo., M. Auty, Ltd., Tynemouth.

RAYS OF LIGHT.

By T. C. HEPWORTH.

A PERSON of ordinary attainments would consider himself very much aggrieved if doubts were cast upon his ability to describe in plain language any of the common things he saw around him. But if he were asked to give a definition of "Light" he would, unless an interest in scientific matters had prompted him to dip into the text-books on the subject, find great difficulty. He would probably feel vexed that he was ignorant about a thing which is so universal. "But stop," he would say to himself, "is it a thing? We cannot touch it, we cannot feel it; we can hardly be said to see it, although it enables us to see. Of what does this light, which is so necessary to our happiness, health, and well-being, consist?"

We may be quite sure that this is a question which perplexed man as soon as he began to trouble his mind with regard to the elucidation of problems concerning nature. Lucretius, a Latin poet and philosopher, who lived half a century before the dawn of the Christian era, imagined that the things which the eye observed threw off tiny images of themselves—little photographs we might call them—which entered the eye. Many centuries later another theory, which found favour with the great Sir Isaac Newton, called the *emission* or *corpuscular* theory of light, was generally accepted. This theory supposed that tiny particles (corpuscles) passed from the luminous body to the eye. One theory holds good until a better one takes its place, and although the corpuscular idea, endorsed as it was by one of our greatest philosophers, seemed at that time to rest on a sure foundation, it proved to be inconsistent with certain observed phenomena, and now it has been superseded by common consent by the *undulatory* theory of light. Instead of particles of rarefied matter proceeding from the luminous body, the modern theory suggests that light is transmitted to the eye by vibrations, much in the same way that sounds are transmitted to the ear. The sound of a drum at no great distance will reach a man with startling effect, but he will know well enough that no part of that drum is propelled through the air to him. The vibration of the parchment is transmitted to the air in the immediate neighbourhood of the instrument, and the sound travels as a wave, or undulation, to the point where he happens to be. It is the same with light; but light is not dependent, like sound, upon the presence of air, for light reaches us from the sun, which is many millions of miles away, and from orbs far more distant, and we know that at a distance of comparatively only a few miles above the surface of the earth the air ceases to be. Another difficulty which has to be met is found in the circumstance that light freely penetrates liquids and certain transparent bodies, such as glass, where obviously there can be no free air to vibrate. What can it be, therefore, that, thrown into wavelike motion, produces in our visual organs the sensation which we know as light, and which brings with it benefits which are to us of such inestimable value?

It is assumed that there is, pervading all space and all things, an extremely thin and subtle medium known as *ether*, which, under the influence of any luminous body, can be thrown into vibrations,

and that these vibrations reaching the organ of sight, transmit to the brain the sensation known as vision. This is the theory which seems to fit in best with the various phenomena which have been observed and recorded. But it is only a theory, and may, like others, be destined to be superseded some day by something which may be considered better. It may be noted here that the sense of vision can be excited quite independently of the presence of light. The optic nerve, if stimulated by the action of electricity or by a blow, or even by mere pressure on the eyeball, will give rise to brilliant flashes and curious figures in a room which is totally dark. A Parisian scientist has lately been investigating these phenomena, and has asserted that by their aid it may be possible to give to the blind something equivalent to ordinary sight.

Photo: T. C. Hepworth.

FIG. 1.—RYDAL WATERFALL: A STUDY IN REFLECTION AND SHADOW.

However this may be, vision is brought about normally by the aid of light, and the optical apparatus by which we see may to a certain extent be likened to the photographic camera. That is to say, there is in front of the eyeball a lens, the necessary alterations in the focus of which, according to the distance of objects from the eye, are brought about by the action of certain muscles. There is the *iris*, or diaphragm, for regulating the amount of light entering the eyeball, and there is the *retina*, or screen, upon which the image of objects is depicted, after the manner of the focussing screen or ground glass, which forms part of the camera. Upon this "retina" there is a marvellous network of blood-vessels and nerves, and among them are tiny processes which, when magnified, assume the appearance of rods and cones. The light acts in some wonderful and unexplained manner on this delicate apparatus, and communicates by the optic nerve with the brain, giving us the great boon and delight of vision.

There are certain terms used with reference to the action of light which it may be convenient to refer to, for they are often used wrongly. For example, it is a common experience to hear persons speaking of the *shadows* thrown by trees and other objects in water when they really mean *reflections*. In the accompanying photograph of Rydal Waterfall (Fig. 1) the rocks and foliage on the right-hand side of the picture are plainly shown *reflected* in the pool below, whilst at the

same time a dark shadow is thrown by the sunlight across the surface of the water. *Reflection* is also often confounded with *refraction*, although the two words have distinct and very different meanings. We have in our every-day lives examples before us of the *reflection* of light. Long before the sun rises in the east the sky in that part of the heavens is illuminated by a constantly increasing glow of light which is reflected to the earth by the atmosphere. Were there no atmosphere to thus reflect and soften the sunlight, the change from night to day would be almost as sudden as a lightning flash. Every mirror gives an image by virtue of reflection, and by holding a lighted candle near its surface we shall find that there are two distinct reflections, one from the front and the other from the silvered side of the glass.

It was probably the accidental observance of reflection which first gave the hint of the possibility of the illusion known as "Pepper's Ghost." More than thirty years ago this optical illusion took London by storm, and, simple as it was in theory, it puzzled everybody. A living man was seen on the stage, which was otherwise empty, and presently by his side would appear, out of space so it seemed, a shadowy figure, which moved about and spoke. At the same time, it eluded all efforts to capture it. and it was slashed through and through with a sword without coming to any harm.

"Pepper's Ghost" was summoned from the vasty deep through the medium of such a prosaic thing as a sheet of plate glass. It was, in fact, a reflection transferred to a stage, with means provided for brilliantly illuminating the object to be reflected, which object was destined to perform the *rôle* of ghost. It is a peculiarity of images reflected from plain glass or from mirrors that they appear to be as far behind the glass as the real object is in front of it. It is this peculiarity which caused little Alice to see a complete room "through the looking-glass," and the efficiency of "Pepper's Ghost" depends upon the same phenomenon. The principle involved in the illusion is shown in a very simple manner in Fig. 2. A sheet of glass is placed across a table at an angle of 45°, and behind it, supported on a book, is a carafe of water. In front of the glass is a candle, which is seen, as a "ghost," burning in the middle of the water. In arranging the apparatus to produce illusory effects, the real object—in this case the candle—would, of course, be screened away from the spectators, the reflection, or ghost, only being visible. When the ghost illusion was first exhibited in London, the glass sloped towards the audience, and the illuminated

FIG. 2.—THE PRINCIPLE OF "PEPPER'S GHOST."

A sheet of glass making an angle of 45° with the table lies between the water carafe and the burning candle. The result is that the candle appears to be burning in the carafe.

figure was situated beneath the stage. The apparatus is capable of much variation, and many clever illusions have been contrived by the help of either plain glass or mirrors, and sometimes by the two combined.

In Fig. 3 we find a kind of "Pepper's Ghost" arrangement put to a decidedly practical use. The glass in this case is set upright across a table, but at right angles to its edge. On one side is placed a drawing to be copied, and on the other a sheet of blank paper. The draughtsman sitting at the table can see in the glass a ghostly image of the drawing on the blank paper, and it is not difficult to trace the lines of the image with a pencil. In this way it is possible to get a correct copy of a picture with the greatest ease, the only disadvantage being that it is reversed, "as in a looking-glass."

FIG. 3.—DRAWING FROM A REFLECTED COPY.

The sheet of glass which gives the reflection is placed upright upon the table at right angles to its edge.

A very beautiful instrument, which depends upon reflection for its action, is the kaleidoscope, invented by Sir David Brewster. By means of three reflecting surfaces and a revolving trough containing fragments of coloured glass, etc., the most beautiful symmetrical designs are produced. When this instrument was first introduced, nearly a quarter of a million were sold within three months. Most persons doubtless regarded it as a pretty toy, but the kaleidoscope is in reality a carefully thought out scientific instrument.

An appliance of far higher aims, and one which also depends upon reflection for its efficiency, is the silvered glass reflecting telescope. This instrument is also known as the Newtonian telescope, and, briefly, it consists of a tube with a concave mirror at the base, the cone of rays from which fall upon a plane mirror which reflects them into the eye-piece set in the side of the tube. At one time the mirror was made of a hard alloy called *speculum metal*, but this had many disadvantages, and the material now used is glass, which is silvered on the surface. This surface silvering of glass is common in nearly all optical instruments in which mirrors are employed, so as to avoid double reflections.

It is a matter of common observation that sight travels in straight lines. A ray of sunlight, rendered visible by means of the motes floating through the atmosphere, proceeding through a chink in a door, looks like a bar of gold; nothing could be straighter, but if that light ray passes into a denser medium its direction is at once changed—it is *refracted*. This is well seen by placing a coin at the bottom of an empty basin and standing at such a distance from the vessel that the piece of money is out of sight. If the bowl be now filled with water, the coin, before

invisible, comes into view. For the same reason an oar dipping from a boat into the water appears to be broken at the place where it touches the surface. In Fig. 4 we see two bowls each with a coin at the bottom, but while one is filled with water the other is empty except for the coin. The apparent change of position of the coin in the vessel filled with water is well shown. The water is rendered more powerfully refractive if we increase its density by the addition of a salt, but crown glass would represent a denser medium still, and this in its turn would be exceeded in its refractive power by flint glass. All lenses owe their virtue to this property called refraction, and hence a telescope furnished with lenses, which is the more common form of that wonderful instrument, is known as a refractor, as opposed to the reflecting instrument already briefly described.

FIG. 4.—AN EASY COIN TRICK.

A half-crown is placed in each of the two glass bowls. The observer stands at such a distance that the coins are invisible to him, then one bowl (A) is filled with water. The coin immediately comes into view.

But perhaps the most wonderful and far-reaching in its results of all refracting instruments is the spectroscope, which has been well defined as an implement in which the action of a prism or combination of prisms is best studied (Fig. 5). It is a comparatively new instrument, although the original observation upon which it is based was made by the great Sir Isaac Newton more than two centuries ago—namely, in 1675 A.D. Refraction through an ordinary sheet of glass is not noticeable, because the ray of light is bent out of its course merely through the thickness of the glass, and, on emergence, resumes its former direction; but if the ray be sent through a prism the effect is very different. In Sir Isaac Newton's historical experiment, he admitted a beam of sunlight through a hole in the shutter of a darkened room, and placed in the path of that beam a glass prism. He then noted that the ray was not only refracted, but was spread out fan-wise into a beautiful band of colour, this band being thrown upon a white screen in the form of a rainbow-tinted ribbon. This coloured

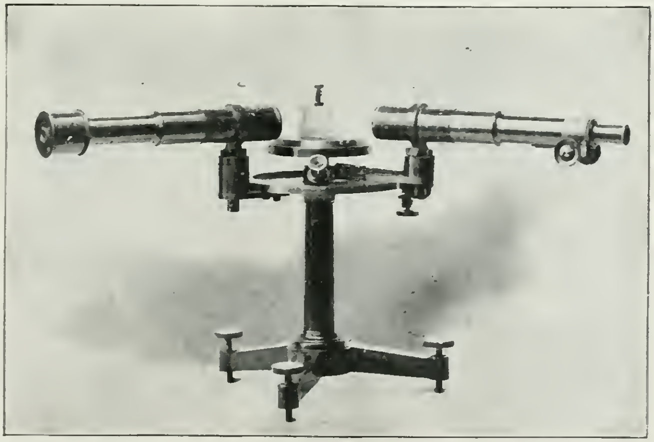


FIG. 5.—THE SPECTROSCOPE.

band of light is known as the solar spectrum. By the action of the prism the white light is broken up into its constituent coloured beams, and if, by suitable means, the colours are made to coalesce once more white light is produced. The rainbow might be correctly described as a spectrum in the sky, for it is formed by means of refraction induced by the falling raindrops. Similar prismatic effects are observable with the cut-glass ornaments of the old-fashioned glass chandeliers and lustres ; we also see them often on the margin of bevelled glass window-panes and on cut stoppers of decanters It need hardly be pointed out that diamonds and other cut stones used by the jeweller owe their beautiful play of colour to the same cause.

Newton used a round hole in the shutter of his room when he made his famous experiment, and the coloured images of this hole overlapped one another on the screen and made a continuous band. No advance was made until the year 1802, when Wollaston made a most important modification of the experiment by using a fine slit through which he admitted light to the prism. He then found that the spectrum afforded was no longer continuous, but that it was crossed by innumerable dark lines. Fraunhofer, by observing the spectrum through a telescope, was able to map out the principal of these lines, and they are now known as Fraunhofer's lines.* The spectrum is in reality a series of images of the slit through which the light comes, and, as each colour has a different degree of refrangibility, these images are spread out into a ribbon, the presence of the dark lines showing that there are certain rays of definite refrangibility which are absent from the sunbeam and which are therefore expressed by lines of darkness. Fraunhofer employed lenses of different material, both solid and liquid ; but these lines always persisted, and he found them, too, in the light from the moon and the fixed stars ; but he noted that no two of the latter exhibited exactly the same spectrum. Another notable advance was made by Simms, who placed a lens between the source of light and the prism, thereby making the rays parallel, and producing a much purer spectrum. These various improvements were embodied in the instrument now known as the spectroscope, a simple form of which is shown in Fig. 5.

The instrument consists of a solid metallic base with a central pillar, upon the top of which is a circular table. In the centre of this table is clamped the prism ; on the right-hand side is a telescope for viewing the spectrum ; and on the left hand is the tube carrying at its end the adjustable slit to admit the light, and a lens to render the rays parallel before they reach the prism. When the instrument is in use a black cloth is loosely thrown over the ends of the tubes and the prism in order to shut out all extraneous light. The only light that can then enter the instrument is through the narrow slit at the end of the left-hand tube.

Before we go further it will be useful to note that long before the invention of the spectroscope it was known that certain substances would impart different colours to flame. Much of the beauty of a firework display depends upon this circumstance, salts of copper affording a blue tint ; salts of strontium, red ; salts of barium, green ; and so on. Sir John Herschell examined such coloured flames by means of the prism in 1822, and he made the pertinent remark that "the colours thus communicated by the different bases to flame afford in many cases a ready and neat way of detecting extremely minute quantities of them." Such colours can be made to tinge the flame of a Bunsen gas-burner by intro-

* *See* CASSELL'S POPULAR SCIENCE, Vol. I., p. 518.

ducing into it a platinum wire holding a bead of the salt to be examined. Common table salt, which is the chloride of the metal sodium, will afford the most convenient instance of obtaining one of these monochromatic flames, a little of the compound sprinkled on the wick of a spirit lamp being all-sufficient for the purpose of experiment.

With such a salted spirit lamp Fox Talbot made several noteworthy experiments, and he, too, was struck with the same idea as that of Herschell, for he writes, "If this opinion should be correct, and applicable to the other definite rays. a glance at the prismatic spectrum of flame may show it to contain substances which it would otherwise require a laborious chemical analysis to detect."

But what did Fox Talbot see in this salted flame, when he observed it by means of a prism, to induce him to be prophetic ? He would see, instead of the rainbow-coloured ribbon which the instrument shows when presented to the light of the sky, nothing left of it save a single line of vivid yellow. If the spectroscope used is of sufficient dispersive power, this sodium line will be seen to be double, but it is distinctive of the metal sodium. And so delicate is this test of its presence that it has been estimated that the spectroscope will detect as little as the one-hundred-millionth part of a grain. In fact, the difficulty is to banish this aggressive sodium line, for common salt is so generally diffused around us that we cannot escape from it. For example, if a platinum wire be held in a Bunsen flame until all the salt has been expelled from it, that wire, if exposed to the atmosphere for a minute or two and again placed in the flame, will once more indicate that it has gleaned enough sodium from the air to give the tell-tale line. Salts of strontium, which, we have seen, are used by the pyrotechnist to produce red light, give several distinctive red lines in the spectroscope, and one blue one. Calcium also gives a red colour to the flame, but its spectrum is quite different from that of strontium. And so we might go on to describe the various appearances given by the different metallic salts. Suffice it to say that the discovery of many of the elements is due entirely to the spectroscope, and it is difficult to imagine any other way in which their presence could have been ascertained. That wonderful thing called radium, which at present is agitating the minds of scientific men throughout the civilised world, so different is it in its properties from every other substance known, was detected because of the strange lines seen in the spectroscope when a certain sample of pitch-blende—an ore found in Saxony containing many metals—was examined spectroscopically. Tons of the ore furnish only a few grains of radium, so that its price works out roughly at something like £15,000 per ounce.

As we have already seen, the lines of darkness in the solar spectrum were mapped out by Fraunhofer, and the principal ones he marked with the letters of the alphabet. The sodium line, which we have seen is bright yellow when the monochromatic sodium flame is examined, is represented in the solar spectrum by a double dark line lettered D. And so it is with many of the other metals, each of which gives its characteristic bright lines across the spectrum when examined in a heated state, but is represented by black lines in the solar spectrum. Kirchhoff was the first to point out the reason of this reversal of the lines. By employing a lime-light, and allowing its rays to traverse a flame coloured by sodium, he found that the double D line became black, instead of bright yellow, when seen on the bright background formed by the brilliant incandescent lime, the same effect being produced by treating other coloured

flames in the same way. The conclusion arrived at is that in the envelope of the sun are found certain vapours due to the combustion of various metals known to us on the earth, and that these vapours absorb certain rays, which are the same rays that under other conditions they would emit. In Fig. 6 a larger view of the principal parts of the spectroscope is shown: the glass prism occupies the centre of the picture, the telescope being on the right hand, the tube carrying the lens and slit on the left-hand side. It will be noted that these two tubes are carried on a divided circle, so that they can be placed at any angle and the angular measurements easily noted.

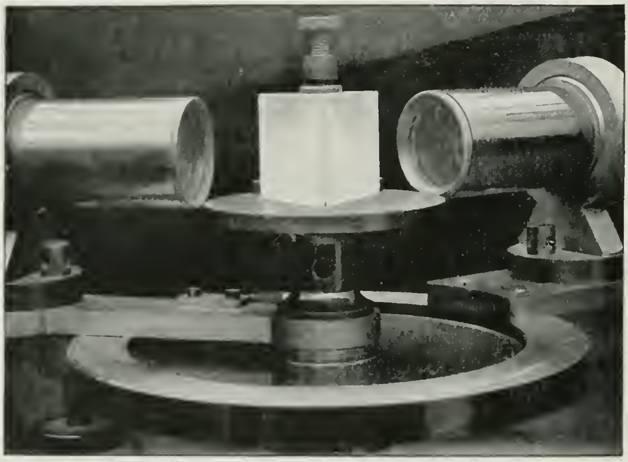


FIG. 6.—A NEARER VIEW OF THE SPECTROSCOPE.

A very dense kind of glass is used in the manufacture of prisms for the spectroscope, for the denser the material the greater is the dispersion—*i.e.* the difference between the bending of the red and violet rays of light. The dispersion can also be increased by employing a number of prisms instead of one. Thus in Steinheil's form of spectroscope there are four prisms placed as shown in Fig. 8, the separation of the coloured images getting greater and greater as they go through each prism in turn. With this form of spectroscope Kirchhoff made his elaborate maps of the solar spectrum.

In Fig. 7 is shown the photograph of a direct vision prism, formed of three glasses which are cemented together. This arrangement is employed for the cheap form of spectroscope, which consists of one tube with an adjustable slit at the end, and which is so small and compact that it can be carried in the waistcoat pocket. In this tube is placed the prism, with a sliding drawer like a telescope, and at the end of the drawer is a lens. The star spectroscope consists of one tube with a direct vision prism, and it is attached to the observing telescope in place of the ordinary eye-piece, when it is desired to study the spectra of the distant stars. Or the spectroscope can be carried on a revolving nose - piece, one arm of which carries the eye-piece, so that either one or the other can be readily brought into use as desired. It will be noted that such an arrangement has long been in use for holding microscopic objectives of varying power.

In order to exhibit spectrum phenomena upon a screen for lecture illustration, the electric light is indispensable, unless the effects are shown on a very inadequate scale. The apparatus consists of the light enclosed in a lantern, a lens, and one or two bottle prisms filled with bisulphide of carbon. Such a prism is shown at the extreme right-hand side of Fig. 9. The advantage of using such a prism is one of economy, the price of a bottle being inconsiderable when compared with a prism of dense glass. At the same time, for accurate results the bottle prism cannot be recommended, although it serves well to illustrate to a

large audience the leading phenomena of spectrum analysis.

When it is desired to ascertain the refractive index of any particular liquid, a much more carefully made form of bottle prism is employed. This is also illustrated in Fig. 9. The prism is made of glass, optically worked to an exact figure, and which therefore becomes an expensive piece of apparatus. It will be seen that this prism has a round hole bored through its sides, which, when in use, are covered by the plates of glass shown lying below it. At the top of the prism is a stoppered hole for the admission of the liquid to be examined. The surfaces of the prism and of the plates of glass are so true that when those plates are placed in position and secured by indiarubber bands, as shown on the extreme left of the photograph, there is no fear whatever of the liquid making its escape.

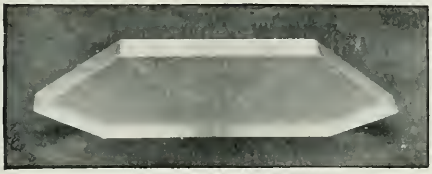


FIG. 7.—DIRECT VISION PRISM.

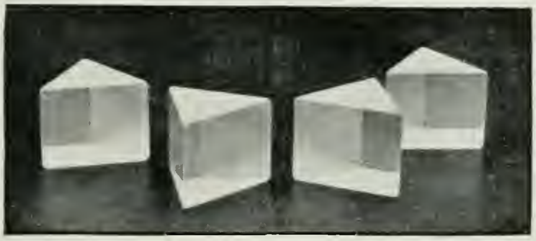


FIG. 8.—SHOWING ARRANGEMENT OF PRISMS IN STEINHEIL'S SPECTROSCOPE.

It may be noted here that the spectrum projected upon the screen is much longer than the portion actually visible. There is an invisible region which extends for a considerable distance beyond the violet end of the band of colour, and another region which extends in the same manner beyond the red end. It is probable that the point where visibility at each end ceases is different for different individuals.

The power of certain gases to absorb or stop rays is shared by liquids and solids. For example, the salts of the element known as didymium, although colourless when in solution, have the power of absorbing certain rays, so that the spectrum is crossed by dark bands. In like manner we may take three coloured solutions—say, one of blood, one of logwood, and another of permanganate of potash. These all look the same to the eye, but they each give very different results when examined with the spectroscope. Such effects are known as *absorption spectra*. It would be easily possible, by comparing a pure port wine with that coloured by logwood, to point out which of the two was adulterated. For such comparisons between different spectra, the spectroscope slit is in the more

D C B

A

FIG. 9.—VARIOUS PRISMS.

A, plates of glass; B, bottle prism; C, more expensive form of bottle prism, with a hole bored through; D, plates of glass placed in position and fastened with indiarubber bands.

perfect instruments furnished with an extra prism outside the slit, so that two spectra can be seen in the field of view at one time. This extra prism can be turned aside when it is not wanted.

It does not matter how distant the source of light may be, so long as its rays can be made to enter the slit of the spectroscope. Hence it is found possible to analyse the light afforded by the fixed stars, which are at an immeasurable distance from our earth. Sir Norman Lockyer, in his "Studies in Spectrum Analysis," writes: "All the stars of heaven have revealed to us their constitution—that is to say, the elements of which they are built up—at what temperature they exist, and a great deal of their meteorology, by which I mean the nature and extent of their atmospheres, and the way in which their atmospheres vary from cycle to cycle."

We thus see that the seed sown by Sir Isaac Newton, and so lovingly tended by those who followed him, has resulted in additions to knowledge of incalculable value, knowledge which is not confined to the limits of our own planet, but which penetrates the immeasurable depths of space. If the great philosopher who first studied the prism could have foreseen the wonders of spectrum analysis, he would indeed have rejoiced. As it was, he thought but modestly of his own labours. This we may glean from the following extract from his writings:

"I do not know what I may appear to the world, but to myself I seem to have been only like a boy playing on the sea-shore, and diverting myself in now and then finding a smoother pebble, or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me."

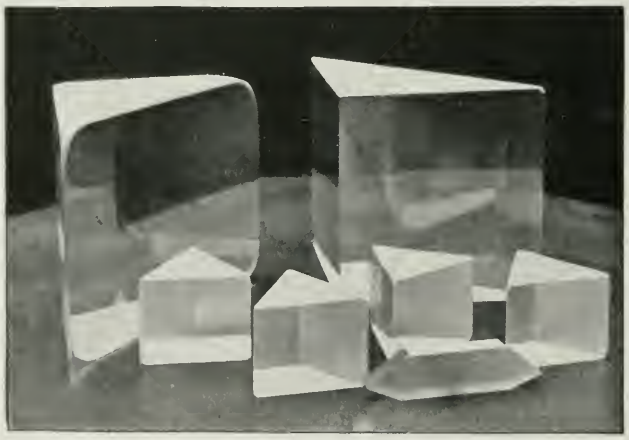


FIG. 10.—A GROUP OF PRISMS.

BURNT OUT VOLCANOES.

ALTHOUGH we have in Britain no active volcanoes like those which in Southern Italy have spread desolation over huge tracts of country, or like those in the West Indies, which more recently, by their awful violence, have called the attention of the entire world to the havoc that they have wrought,* we have plenty of evidence in the condition of our rocks that in past times—possibly ages before the coming of man—this country was subject to volcanic action. First, we may refer to certain hot springs which may fairly be assumed to be in some way connected with volcanic phenomena. By far the most important of these is found at the city of Bath (Fig. 1). There are here four springs—which apparently rise from the same source—the waters of which have a temperature that is remarkably constant at all seasons of the year, namely, from 97° to 120° Fahr. It has been calculated that the water rises as from an artesian well, from a depth of about 3,500 feet, or about three-quarters of a mile from the surface. The daily flow is said to amount to nearly 185,000 gallons, and the water has always been prized for its medicinal qualities. That the springs were valued as far back as the Roman occupation of Britain is proved by the discovery of the remains of Roman

Photo: T. C. Hepworth.

FIG. I.—THE CITY OF BATH.

The city is set in a charmingly wooded valley of the Avon. Tradition has it that it was founded by a British prince, Bladud, in 863 B.C., and it is certain that the efficacy of its chalybeate springs induced the Romans to build huge baths here in the first century of the Christian era. Portions of these baths were uncovered in 1755 and 1881. (See Fig. 2)

* Cassell's Popular Science, Vol. I., p. 428.

baths, which of late years have been laid bare (Fig. 2).

In the opinion of no less an authority than Professor Judd, the enormous amount of heat of which the earth's crust is relieved by this outpouring of water at Bath may equal that of a volcano of considerable size, which, although much more violent in its action, is at the same time intermittent. The same writer has calculated that since the time of the Romans the amount of solid matter dissolved in, and brought up by, the steaming water at Bath would, if collected, form a cone equal in height to Monte Nuovo, the volcano on the shores of the Bay of Naples, which came into existence between three and four hundred years ago.

There is a model at the Victoria and Albert Museum, South Kensington, which shows the way in which a volcanic cone is formed. It consists of a table with an orifice in the centre in connection with a strong air-blast. When bran, sawdust, or other light material is fed into the supply pipe, it is blown up into the air for a couple of feet or so, and then, descending, gradually forms a hill around the opening.

Photo: Graphotone Co., Enfield.

FIG. 2.—REMAINS OF THE OLD ROMAN BATHS AT BATH.

In a natural volcano a similar cone is formed on an enormous scale, and if we were able to cut into it and obtain a vertical section, we should have no difficulty in recognising the layers of lava, pumice, and ashes of which it is composed. We find in our own country no very distinct craters, for such a long period has elapsed since active volcanoes were to be found here that the heaps of ashes and

other material have long ago been swept away.

In many parts of our country we can find evidence of past volcanic action by the presence of eruptive rock, which is of so hard a nature that it has withstood the wearing action of centuries. In Fig. 3 we have a photograph of a boss of basalt, known as the "Stack of Scarlett"; it forms a noticeable promontory of Poolvaash Bay ("Bay of Death") in the Isle of Man. The Isle of Staffa—otherwise known as the "Island of Columns"—is remarkable for its basaltic formation, and in certain places the stony columns are seen to be bent like the ribs of a ship—evidently by pressure when in a soft, heated state, much in the same way that sticks of warm sealing-wax may be bent. "The Giants' Causeway," in the North of Ireland, is another place remarkable for columnar basaltic rocks.

Photo: T. C. Hepworth.

FIG. 3.—"THE STACK OF SCARLETT."

This is a very rugged mass of basalt in Poolvaash Bay ("Bay of Death"), Isle of Man.

Returning once more to Poolvaash Bay, we find here abundant evidence of past volcanic action. The limestone is of a pale grey colour, and is full of fossils. But the intrusion of volcanic rocks is everywhere noticeable, and much of the limestone has been converted by heat and pressure into a crystalline form. Here it is that a valuable black marble is found, and from this spot the slabs were quarried two hundred years ago which were destined to form the steps of St. Paul's Cathedral.

There is one place in this bay which has every appearance of having at one time formed the site of a small volcanic vent (*see* Fig. 4). A nearer view of it is shown in Fig. 5.

Mr. Cumming, who is an authority on the rocks of the Isle of Man, considers that in past ages so much heat has been evolved, accompanied possibly by the evolution of acid gases, as to entirely alter the character of adjacent rocks. It is difficult, he writes, sometimes to determine whether a given specimen is altered limestone or true trap. In a more easterly portion of the southern coast we find evidence in the crystalline eruptive rocks of past

volcanic action. In one place especially these are rocks contorted in a remarkable manner by the enormous pressure to which they have been subjected (Fig. 6). In places the coast here rises to a height of 300 feet, and the rocks are of the most varied forms. In the neighbourhood of those vast rents in the cliffs which are known as "the chasms," the schist is bent about in a peculiar undulating form, as may be seen in Fig. 7; while close by, in the form of a bifurcated stack, called the "Sugar-loaf Rock" (Fig. 8), the bedding is so nearly horizontal that the rock, although of the same character, might be mistaken for limestone.

Photo: T. C. Hepworth.

FIG. 4.—CRATER OF AN OLD VOLCANO IN POOLVAASH BAY, ISLE OF MAN.

Photo: T. C. Hepworth.

FIG. 5.—NEARER VIEW OF THE SAME CRATER.

If we wish to behold extinct volcanic craters that have been better preserved from the various agents of denudation, we must, to find the nearest examples visit Auvergne, in Central France. Of this interesting district Professor Bonney writes:

"Here, more easily than in any other place readily accessible from England, volcanoes can be examined while their natural features are comparatively fresh and unchanged, yet without interference from the sulphurous exhalations and discharges of an active vent. Here we have

our "subject," to use the language of the surgeon, ready for us in the first stage of dissection, giving us the clues by which we can interpret the more obscure signs of volcanic action in the earlier geological periods.

"We cannot precisely determine at what date the volcanic fires became extinct in Auvergne. Ages elapsed between the first and the last outbursts, during which there were probably long intervals of quiescence, and it is likely that the subterranean furnaces would not cease action simultaneously over the whole region, but would break forth, now here, now there, with an expiring sputter. There is some reason to think that one or two isolated outbreaks occurred as late as the fifth century of the present era, though that is a matter on which there is much dispute. At any rate, there is a passage in the writings of Sidonius Apollinaris, Bishop of Clermont, in Auvergne, and another in those of Alcimus Avitus, Archbishop of Vienne, which must either be accounted pieces of the most exaggerated bombast or must record some of the phenomena of a volcanic eruption.

"Before describing a few of the facts which this region teaches us, a sketch of its geological history may be in itself instructive.

"It is not till the Tertiary Period is considerably advanced that we meet with any very distinct records of volcanic action in Auvergne. Then, in the Miocene epoch, the inequalities of the plateau appear to have been occupied by large fresh-water lakes, the surface of these being probably some 2,000 feet above the present level of the sea. At this time volcanoes broke forth on the plateau, ejecting mounds of scoria, and flows of lava, till at last the shores of the lakes, and the marls which had gathered be-

Photo: T. C. Hepworth.

FIG. 6.—ROCKS CONTORTED BY VOLCANIC ACTION: AS SEEN IN THE ISLE OF MAN.

neath their waters, were in many places sealed up beneath great sheets of basalt. Then the level of the lakes was gradually lowered. As the water fell, the tributary streams, which took their rise among the volcanic hills, deepened and enlarged their channels, until the foundation rock was again laid bare, and portions of the basaltic sheets were left, forming bastion-like crags high above the re-excavated beds of the lakes and the floors of the glens.

"The volcanic energy appears to have been for a while quiescent. At last, however, it awoke, and a number of volcanic vents opened in a sporadic way; some upon the plateau, some on the floors of the newly excavated valleys. These, though discharging scoria and lava in considerable quantities, were smaller than those formed in the preceding period; they resembled the volcanoes of the Phlegræan Fields rather than the cone of Vesuvius—attaining no great elevation, emitting no extensive flows of lava. They exhibit no marked signs

of physical change. Vegetation has masked or rain has furrowed some of the cones; lichen and moss, herbs and shrubs, have occasionally softened the asperities of the lava stream, and in some cases the river has again carved for itself a passage through the obstacles, and has regained its ancient channel; but, on the whole, the district remains very much in the condition in which it was when the last shower of ashes was ejected from the last expiring crater.

"These volcanic hills, in the Auvergne district, bear the name of Puy. We will take our examples from the chain which studs the eastern edge of the granitic plateau, near to the town of Clermont Ferrand. It will at once be observed that in these hills there are marked differences of outline, the majority being truncated cones, the usual form of volcanic craters; while a few are flattened domes, something like—to use an unpoetical simile—the upper half of a plum-pudding. The latter, such as the Puy de Dome, the highest summit of the group, on examination, prove to be without sign of a crater, and to consist wholly of a peculiar variety of trachyte. Their precise geological age and mode of formation are uncertain, but probably these hills (with other trachytic masses of greater size) are much older than the adjoining cones.

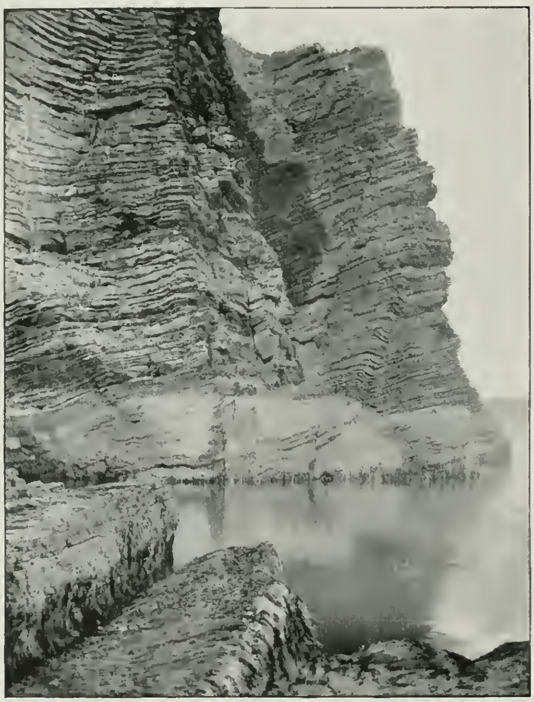


Photo: T. C. Hepworth.

FIG. 7.—MORE ROCK TWISTINGS IN THE ISLE OF MAN.

The abundance and extent of these contortions afford certain evidence that at one time, probably in a very remote age, the Isle of Man was in the throes of fierce volcanic action.

"Of these cones one of the most perfect is called the Puy Pariou. Viewed from the south it appears a well-defined cone, rising some 700 feet above the base, with steeply sloping sides (the angle being about 35°), wholly composed of volcanic scoria. Grass and ling have in many places grown over this, but there are others still bare. On reaching the summit we find ourselves on the rim of a perfect crater, some hundred yards deep and about ten times as much in circumference, with the ridge still in places so sharp that there is hardly room to stand upon it. Herbage clothes the interior of the crater, and, as Scrope observes, it is a singular spectacle to see a herd of cattle quietly grazing above the orifice whence such furious explosions once broke forth.

"There are places also in this district where the under part of a lava stream may be seen no less plainly than the upper. The brooks have re-excavated their channels, the stone has been quarried, or some other cause has given us a section. One of the most interesting of these is in a cutting on the road a mile or so south of Clermont Ferrand. Here

a lava stream has flowed over cream-coloured marls, with an occasional stony band. On these it rests with a most irregular base, rising and falling some fifteen feet in about thirty yards, crushing and crumpling the softer beds, thrusting into them tongues and little veins, and entangling fragments of them in its mass. The marl has been baked by the heat, though for no great distance, and is changed, for a space varying from a few inches to a yard, to a brick-red colour. The lava has a rough, slaggy crust at its base, in thickness from one inch to six inches, after which it passes quickly into a dark compact rock, cut by irregular curving joints. Here and there it becomes suddenly scoriaceous, looking as if in rolling along it had enveloped fragments of its own crust, which, after solidifying and resisting for a while, had ultimately given way to the pressure of the still liquid mass behind.

"Besides the above examples, types only of numerous instances, we find cones and lava streams which have been more injured by the attacks of time. But as in this region we find all gradations, from the ruin to the complete structure, we are able to interpret the less by the more perfect; and as the last bear the closest possible resemblance to the cones and craters of volcanoes still in activity, we obtain a clue which we can apply to the more obscure volcanic remains of a more remote past."

Photo: T. C. Hepworth.

FIG. 8.—SUGAR-LOAF ROCK, ISLE OF MAN.

Note the nearly horizontal character of the "bedding" here, and compare with the contortions in Figs. 6 and 7.

THE HONEY BEE.

THE order of Hymenoptera is one of the most important of the class *Insecta*, and the sub-order *Aculeata* a highly interesting section. Here it is that the honey-bee is placed by entomologists, and with it the ants and the wasps. As honey gatherers, the bees would have a considerable claim on our attention, but the bee has a great part to play in Nature's scheme of flower fertilisation, while the naturalist pure and simple points to the high degree of intelligence displayed by the bees, and the student of social problems finds much to interest him in, and much to learn from, what goes on inside the hive.

FIG. 1.—INMATES OF A BEE HIVE.

A, the queen, the mother and ruler of the family; B, the worker bee, a female of incomplete sex, who gathers the honey, tends the young, and does the work of the hive generally; C, the drone or male bee.

Aristotle, Pliny, and Virgil all wrote about bees, but they did little more than gather up the various legends connected with them, and their reputed habits. With these, space does not permit us to deal.

The legitimate inhabitants of a bee-hive comprise four sets of individuals—namely, the queen bee, the workers, the drones, and the young in their various stages (Fig. 1). Upon the workers all the labour—both inside and outside of the hive—devolves. The function of the queen is simply to lay eggs, while that of the drones is to fertilise the queen. Let us select for observation a hive in early spring, when the bees are commencing to resume their active work. The inhabitants of the hive in question are the queen bee, and a more or less numerous body of workers. The latter, warned by the increasing sunshine that the time of flowers has come, will probably soon begin to prepare the waxen cells known to everyone as honey-comb. The way in which these cells are formed has not only been most carefully studied, but has given rise to numerous controversies, into which we need not enter, but content ourselves with briefly describing the chief points in the work of construction.

For the production of wax, the bees fill themselves with honey, and then rest without moving, but suspended to each other in a series of festoons (Figs. 2 and 4), for about twenty-four hours, during which the formation of wax is going on. The wax appears in the form of thin scales, which lie in the wax-pockets, as certain membranous bags situated between the rings of the under side of the abdomen are called (Fig. 3). When the wax has been produced the worker goes to the place where the comb is being made, and clears a space to work in; it then seizes a scale of wax with one of its hind legs, passes it

on to one of the front legs, which conveys it to the mouth, where it is chewed and mixed with a frothy exudation

FIG. 2.—WAX-PRODUCING WORKERS.

till it has acquired the necessary pliability and tenacity. The bee then deposits the morsel of prepared wax against the place where it is to be fixed, and proceeds to prepare the rest of the wax that she has secreted till all is used up, when she

FIG. 3.—A WORKER : ENLARGED.
Notice the plates of wax appearing between the segments of the abdomen.

retires, and her place is taken by another. In this manner the foundation of a new comb is laid. It will be remembered that the combs hang perpendicularly, with the mouths of the cells horizontal.

The wax-producers having laid down the supply of wax, the other set of workers come and begin the moulding of the cells (Fig. 5). The comb (Figs. 6 and 7), as already said, is to hang perpendicularly, and forms, as it were, a sheet of wax, the two faces of which are covered with cells, the bottoms of the cells of the one side being in close approximation to the bottoms of the cells

FIG. 4.—WAX-PRODUCING WORKERS IN THE ACT OF SECRETING.

of the other. The cells are fashioned by the builders in the following manner :—A bee takes up its position about the middle of the little wall of wax left by the wax-producers, and moulds with its mandibles a cavity to form the base of a cell. After working for a few minutes it is succeeded by another, who continues the work, deepening the hole and heightening the walls. After a time this bee gives place to another, and so on in succession, till perhaps more than twenty bees may have been engaged at this one cell. After

this first cell has attained a certain size other bees commence, on the *opposite* side of the wall of wax, with the foundations of *two* cells, and continue working at them in succession till a certain height has been reached. The work is carried on till all the bases of the first row of cells have been accurately formed, after which they are polished, while other bees are commencing the second row. In the meantime the wax-producers have been busy laying down fresh wax for the builders to work with, and so the comb increases both in length and breadth, till it finally assumes the parallel-sided form that it possesses when finished. After the bases of some rows of cells have been made and polished, the next work is the construction of the walls of the cells, which is done by the builders in the same manner as they

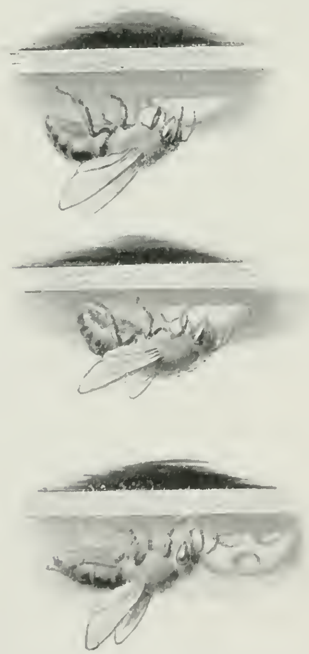


FIG. 5.—THE GROWTH OF THE CELL.

formed the bottoms of the cells. It is to be noted that the cells of the first row are five-sided, but that those of the other rows are six-sided.

Now we must very briefly consider a matter which has given rise to endless debate amongst students of bees. Are the cells mathematically exact? Could one bee alone form such a cell? And are the bees guided by intelligence or by "instinct"? On all these points very diverse opinions have been advanced.

In the first place, as to the mathematical exactness of the hexagonal cells. It was for a long time considered that the cells were exact; but it has now been proved that an exact cell exists only in theory, and that the cells are all more or less imperfect. In the second place, it is doubtful if one bee could alone form a hexagonal cell; but some authors think it probable that if a single bee constructed a cell it would be round, and not six-sided. Others, arguing from the cells constructed by certain wasps, think that a single bee is quite capable of constructing hexagonal cells. To the third question "Do the bees work intelligently, or are they guided by instinct?" the opinion of the late Mr. Frederick Smith was that they work intelligently, and one of his chief arguments in favour of the intelligence is that they readily make use of the artificial rudimentary comb that modern bee-masters are in the habit of supplying to their bees. This artificial comb consists of a sheet of wax, on each side of which are exact impressions of the base of the natural comb. On these the bees readily erect the cell walls, just as if they themselves had formed the bases of the cells. Mr. Smith was thereby led to form the opinion that we should cease to stigmatise the bee as a "mere machine."

The cells—which have given rise to so much discussion—though they may not be mathematically exact, are at least admirably calculated to economise both material and space. They are six-sided, with the base composed of three lozenge-shaped pieces, and so arranged that the base of a cell on one side is formed of portions of the bases of three cells on

the other side of the comb. The hexagon is one of the three figures of which a number may be packed together without

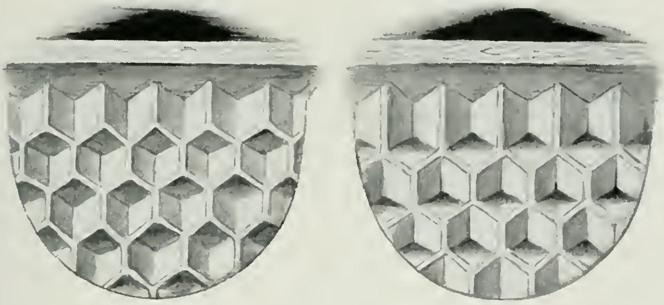


FIG. 6.—SHOWING THE SHAPE OF THE CELLS AND THEIR ARRANGEMENT IN THE COMB.

leaving interstices. The other two figures are the square and the equilateral triangle.

Many a discussion has raged as to the reason for the honey bee adopting the hexagon shape for its cells. The naturalist Buffon was of opinion that the shape was due to the pressure exerted by one cylinder upon another in the comb. This was discredited for a long time, but recent authorities—including Dr. Müllenhof—have reverted to this explanation. Darwin took another line, and demonstrated that the form of the cells was, to some extent, the result of evolution, seeing that some bees build cylindrical cells. His idea was that the circles described by the walls of the cells would, if completed, intersect each other, the site of the one cell being so close to the site of the others. Instead of completing the circles, however, the bees build flat plates at the points where the circles would intersect, and the result is a more or less hexagonal cell. This is both an ingenious and an interesting explanation, but it is quite possible that the compression of closely packed tubes is to some extent a factor.

The ordinary six-sided cells vary somewhat in size, according to the use to which they are to be put. The purposes for which they are constructed are, first, as nurseries for the young; and second, as store-rooms for food. The cells in which the larvæ of the workers are to be reared are about $2\frac{2}{5}$ lines in diameter, while those for the larvæ of the drones or males are about $3\frac{1}{3}$. The latter kind of cells usually occupy a comb to themselves, but we sometimes find them at the sides and bottom of the other combs. The bees, in constructing them, gradually increase the size of the worker-cells in the intermediate rows till the necessary size is reached—that is to say, there is no abrupt transition in size between the worker and the drone cells.

In addition to these hexagonal cells there is another kind of cell, in which the larvæ that are to produce queens are reared. These are quite different in form and size, being considerably larger, and pear-shaped (Fig. 8). They are also not placed horizontally, like the

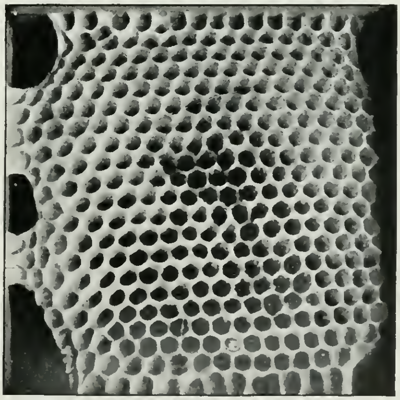


FIG. 7.—THE FINISHED COMB.

The cells have now reached their full depth; they will be filled with honey, and then sealed.

other cells, but vertically, with the mouth downwards. These cells are not composed of such fine wax as the ordinary cells, but of much coarser stuff,

and they require about one hundred times as much material.

Having now seen the nature of the habitation that the bees construct for

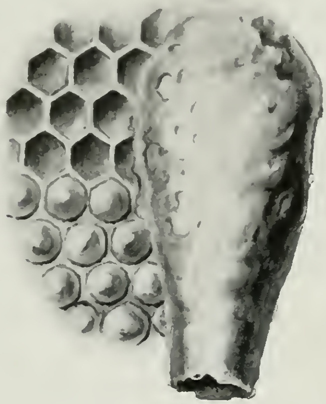


FIG. 8.—A QUEEN CELL.

themselves, we must take a glance at the manners and customs of the inhabitants of the hive, and, without any disrespect for her majesty the queen bee, will begin with the daily life of the workers, as it is by them that all the labours of the community are performed. These are imperfectly developed females, and their work is to construct the interior of the hive (*i.e.* the combs), and keep it in order, to collect food for the community, and to nurse the young.

The cells having been constructed in the way we have seen, the bees lose no time in making use of them. When the queen is moving about laying eggs—which are deposited one in each cell—she is attended by a small retinue (four to twelve) of workers. If from scarcity of cells, or some other cause, the queen, as sometimes happens, lays more than one egg in a cell, the workers in attendance are careful to remove all but one. When the eggs hatch, the labours of the workers are increased, for they have to see that there is in each cell, along with the young grub, a sufficient supply of bee-bread. This bee-bread is composed of the pollen of flowers, which the workers are incessantly engaged in collecting and storing up in cells in anticipation of the needs of the young brood. Before being given to the grubs, the bee takes the pollen into its stomach, where it is probably mixed with honey, and, in addition, undergoes some chemical change. It is then regurgitated in the form of a whitish jelly, and a sufficient quantity placed in the cell with the larva or grub. If we watch a piece of comb in which there is a young brood we may see bee after bee examining the cells to see if there is enough food in them, and where the food has been all consumed a fresh supply is deposited. When the grubs have attained their full size the workers seal the mouths of the cells with a mixture of pollen and wax, the lids being nearly flat in the case of workers, and convex in that of drones. After that, the labours of the workers cease as regards these; for the young bees, when arrived at the adult state, are able to extricate themselves from their cocoons and from their cells.

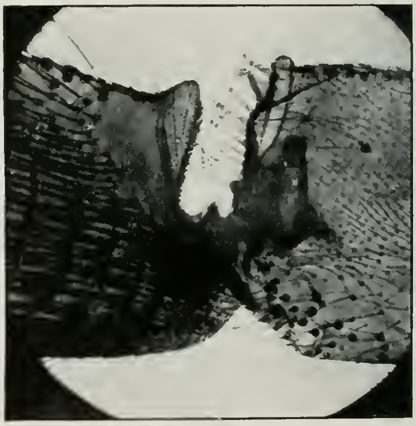


FIG. 9.—JOINT OF POSTERIOR LEG OF BEE, SHOWING TOP OF "POLLEN BASKET."

In addition to their nursing duties, the workers are the purveyors of food for the community. The materials used for food are the nectar and the pollen of flowers; but in addition to these they collect a substance called *propolis*,

a kind of resinous matter commonly found on the buds of such trees as the poplar and birch, which is used for coating the inside of the hive, and for covering up any noxious matter too large for the bees to move, *e.g.* a decaying moth or slug. Like the pollen, it is carried on the broadened *tibia* (pollen basket) of the hind leg of the bee (Fig. 9). When a bee returns from an excursion she hastens to deposit her load. The honey that she has swallowed she disgorges into the cells prepared to receive it, first breaking with her front legs the thick skin that has formed on the honey already in the cell. It requires the contents of the honey-bags of a good many bees to fill a cell. Some of the cells containing honey are left open for daily use, but others are sealed with wax, and reserved as a store for the season when no honey can be collected.

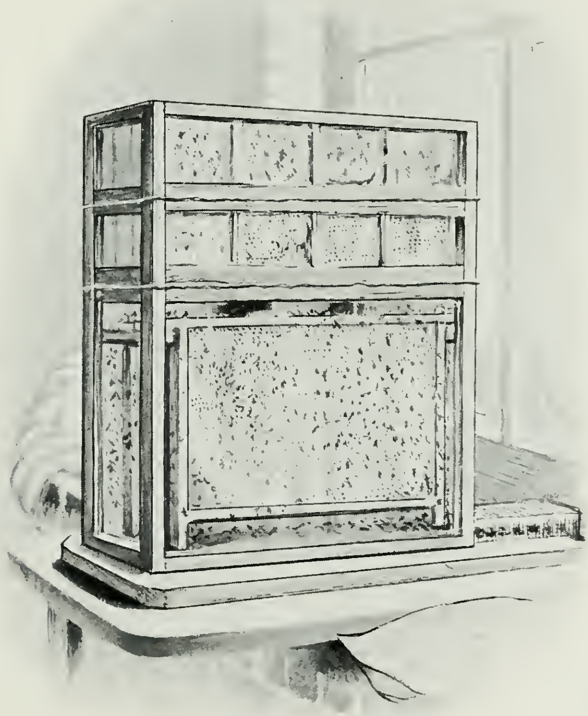


FIG. 10.—AN OBSERVATORY HIVE.

As for the pollen brought back, it is disposed of variously, as circumstances may direct. The bee frequently summons others to her assistance by flapping her wings, and she and they then proceed to empty the pollen-baskets on her hind legs, and prepare the jelly mentioned above. If, however, no bee-bread is required at the moment, the pollen is stored up in an empty cell; then the laden bee puts her two hind legs into the cell, and pushes off the pollen with the intermediate pair of legs. She (or, if too fatigued by her labours, another bee) then enters the cell, and packs the bee-bread into as small a space as possible.

In addition to these duties, the workers keep the hive clean, and also attend to the ventilation. The latter is a very important duty, when we think of the great number of individuals inhabiting a confined space, and it is effected by the vibration of the wings. A certain number of bees stand outside the entrance to the hive, while a still larger number take up their position on the floor of the hive, and, all vibrating their wings together, set up perceptible currents of air. When a bee is tired of this occupation its place is taken by another.

In watching the proceedings in a hive, it will be seen that bees sometimes go to empty cells and enter them head first, leaving only the ends of their bodies protruding. In this position they stay for a considerable time, and there is good

reason for supposing that this is their way of sleeping.

Nothing has been said as yet about the use that bees make of the formidable stings with which they are armed. These are primarily weapons of defence, for the bee is slow to use its sting, much as some unlucky wight may protest to the contrary. The maxim "To be slow to anger" is in the bee's case founded on sound physiological reasons, for the fine barbs of the sting almost invariably cause the latter to be left in the wound, and a bee robbed of its sting is not only harmless, but doomed to an early death. Sometimes, however, it happens that bees from one hive will attack and rob another hive, and fierce battles then ensue between the robbers and the robbed, when stings are freely used.

The cells in which the drones are reared are rather larger than the worker-cells, but in other respects their early history is similar. The drones do not take any part in the work of the hive beyond helping to keep up its heat, and their span of life is not very long. The pairing with the queen, or queens, takes place outside the hive, and, that accomplished, the drone is of no further service. Indeed, the ambitious drone who aspires to be the consort of a queen does not long survive the taking of the nuptial vow. Herein is a warning to those who aim too high. In a busy hive the drones make their appearance in May, and they are allowed to exist until early in August. Then the workers turn upon their erstwhile associates and drive them from the hive to die. It is quite a common sight to see the badly wounded drones crawling painfully about outside the hive that has rejected them. After this massacre the workers search out any male pupæ that may be left in the drone-cells, suck the juices out of their bodies, and drag them out of the hive.

The life-history of the queen bee has now to be considered. As mentioned above, the larvæ that are to result in queens are reared in larger and differently shaped cells from those in which the workers and drones are brought up. But, in addition to this, queen larvæ are fed upon another and more nutritious food than the other individuals, and it seems to be entirely due to this food, as well as to the larger and differently shaped cell, whether the larva will result in a queen or in an ordinary worker. When we consider how different, in many respects, the queens and the workers are, this seems very curious; but it must be remembered that the workers (like the workers amongst ants) are really females, only less developed, and that in some few instances they are able to produce eggs, which result, however, only in male progeny. But that the same kind of larva can be brought up so as to result in a worker, or in a queen, is capable of direct proof, for in hives that have accidentally lost their queen, and where no queen larvæ are being reared, the workers select some of the ordinary worker larvæ (from one to three days old), and feed them with the special *queen food*, or *royal jelly*, and thus raise up a new monarch. In addition to this special food, the larger size and different form of the cell, as well as its supposed higher temperature, are said to be factors in changing the destination of the larva so treated.

In the preparatory states (egg, larva, and pupa), the queen takes a shorter time than the workers and the drones, they requiring, respectively, twenty and twenty-four days, while she needs only sixteen. There is also a difference in the cocoon spun by the queen larva. The worker and drone larvæ make cocoons which completely envelop them; but the queen larva covers only the head, thorax, and first segment of the abdomen.

When the queen has nearly arrived at the adult state, and the pupa is approach-

ing maturity, the workers, who have made the wax at part of the cell so thin that the state of matters within can be readily ascertained, are very careful to watch that she does not make her escape before it is desirable that she should do so. The reason why they do this may be one of several; but before mentioning these we must notice the phenomenon called "swarming" (Figs. 11 and 12). When the population of the hive has increased beyond the capacity of the structure to hold it, a certain portion migrates to new quarters, and the colonists are led by the reigning queen. Before, however, she departs to found the new colony, she lays eggs in the royal cells at intervals of some days (so that the coming queens may not all arrive at maturity at the same time). If, however, the swarming has been delayed for some reason, as through inclement weather, it may happen that the old queen is still in the hive when the first of the young queens becomes adult, and if the two were to meet, a battle, resulting in the death of one or both of them, would be sure to take place. The workers, therefore, keep the young queen in her cell till the old one has departed. But a more frequent reason for her confinement is that the swarm that the young queen is to lead off may not be ready for her, and as, if she were allowed her freedom, she would probably proceed to the other royal cells and put to death her younger sisters, she has to be kept a prisoner. When at length she is allowed to get out the guard of workers still attend her, and prevent her, if necessary, from approaching the other royal cells. If, however, more queens are not required, she is permitted to search them out and kill them.

Photo supplied by Mr. W. B. Webster, Binfield.

FIG. 11.—A FINE SWARM.

Soon after she emerges from the pupa stage the young queen takes her nuptial flight, for marriage with one of the drones of her own hive would be a *mésalliance* and not to be tolerated. After this brief spell of liberty, she returns to her hive, never more to leave it except in charge of a swarm. Her majesty does not believe in plurality of husbands. One mate only does she take, and he is a stranger. The queen bee is amazingly fertile. In the height of the season she will lay from 3,000 to 4,000 eggs per day, and this is continued for days together. From two to three years represents the period of her usefulness, which, by the way, she does not survive.

The reigning queen is treated by her subjects with the utmost care and attention. She has always a retinue of workers

in attendance upon her, and if by any means the hive is deprived of its queen and of the means of replacing her, the bees cease to work, and soon all perish. As we have seen, however, they have generally the means of raising up a monarch if required. A queen that is not fertilised within about three weeks of the date of emerging from the cell will lay eggs, but they only produce drones, or males. Such a monarch is technically known amongst bee-keepers as a "drone-breeder."

This, then, is a brief sketch of the habits within the hive of its legitimate inhabitants. It does not come within the scope of this paper to describe the proceedings of the bees when on their excursions; but before quitting the subject we must notice some of the illegitimate inhabitants of the hive, which are either parasites on the bees or live at their expense.

Photo supplied by Mr. W. B. Webster, Binfield.

FIG. 12.—HIVING A SWARM.

Amongst the parasites is the so-called bee-louse, *Braula cæca* (Fig. 13), a minute, flattish insect, which, though wingless, belongs to the order of the two-winged flies, or Diptera, and is allied to the sheep-tick and

some other animal parasites. It is blind, and clings to the hairs of the bee, and sucks the juices of its body. It is sometimes said that *Braula* is a parasite of the queen bee only ; but this is quite erroneous. It attacks the workers as well, and though often there is not more than one or two (if any at all) upon a single bee, it occasionally happens that the parasites occur in great numbers, and cause much annoyance to their victims.

Bees are subject to an infectious disease known as *Foul Brood*, the work of *Bacillus Alvei ;* this is really the only ailment that British bees have to fear.

Amongst other parasites are species of oil beetles (*Meloë*), allied to the blister beetles or "Spanish fly" (also a parasite in its younger stages on wild bees), whose larvæ or grubs (Fig. 15) have a very curious life-history. The eggs are laid in the ground, and the young larvæ, when they emerge, find their way to flowers frequented by bees. At this stage the larvæ are minute, very active, louse-like creatures. When a bee visits the flower they spring on to it and feed on its juices, and may be carried into the hive. Having arrived there, they desert the bee and eat the honey instead, and, so far as the hive-bee is concerned, their connection with it probably then ceases, as they seem to be unable to live to continue their metamorphoses. Should, however, the bee that they have attacked be one of the wild bees whose larvæ undergo their metamorphoses in closed cells in which a supply of food has been stored up, the beetle grub lives at the expense of the bee grub and its store of food, and finally, after some very curious changes of form, arrives at the perfect or beetle condition.

Other bee parasites include a kind of mite, which is common upon many insects, and also several intestinal worms of a low type. Amongst the latter are two hair-worms (*Gordius subifurcus* and *Mermis albicans*), which are occasionally found inside the bodies of the drones, though how they come there has not yet been explained. In some of their stages these worms frequent water or damp places, and there the eggs are laid. It may be mentioned that it is through a species of *Gordius*, or hair-worm, being frequently seen in water that the curious belief (not yet even altogether exploded) arose that horse-hairs placed in water will turn to eels ! These hair-worms, which are not infrequent in various kinds of insects, are often several inches in length, and it is remarkable how they find room to stow themselves away within the bodies of their hosts.

FIG. 13.—A BEE LOUSE (*BRAULA CÆCA*).

Though blind, this louse is a very troublesome intruder in the hive.

Among the animals which, as they do not feed on the bees themselves, cannot strictly be called parasites, are some moths which are occasionally inhabitants of the hive. The Death's Head, *Acherontia Atropos* (Fig. 14), so called from certain markings on the back of its thorax having a kind of resemblance to a skull, occasionally visits the hives, and feeds on the honey, which it sucks up by means of its proboscis. The squeaking sound which this moth has the power of emitting has been supposed to have a similar effect upon the bees as the cry of the queen bee, and to prevent attack.

In addition to these, bees have other enemies, such as mice and toads, but

as their assaults are usually made outside the hive, a consideration of them

FIG. 14.—DEATH'S HEAD MOTH *(ACHERONTIA ATROPOS).*

does not come within the scope of this paper. Mice may sometimes take up their abode in the vacant space inside the top of bar-framed hives during the winter, but it will almost always be found that the legitimate occupants of the hive are dead.

In conclusion, it may be mentioned that, while in this paper the habits inside the hive of the common honey bee of this country have been very briefly described, there are several other kinds

FIG. 15.—LARVA OF AN OIL BEETLE.

of honey bee which have been domesticated.

Our bee is the *Apis mellifica* of Linnæus (Fig. 1): it is the common hive bee of Northern Europe and of North America. The Ligurian bee, *Apis ligustica*, is frequently kept, and has been introduced into this country, and crossed with the common honey bee. In Egypt and Asia Minor another bee—*Apis fasciata*—has been domesticated; while in other countries yet other species are kept, and there are other wild bees which might be profitably treated in the same manner.

The "Ligurian" queens are more fertile than those of our common brown bee, and the swarms are proportionably larger,* while it is claimed that the workers are more industrious, not being so much given to hanging in clusters outside the hive during hot weather. Even the "busy bee" has its lazy moments.

FIG. 16.—CATERPILLAR OF THE GOAT MOTH.

Owners of "Ligurians" also find that they are easier to handle than the brown bee, and that they are not so ready to use their stings upon the bee farmer. Here yet another belief is exploded, seeing that for a long time after their introduction "Ligurians" were said to be very savage and intractable.

The belief that there is a close connection between the fortunes of the owner of the hives and the bees is a curious one, and yet, in spite of Education Acts, it may still be reckoned with. Many a rustic implicitly believes that if the owner

* About 5,000 bees go to a pound avoirdupois, and a good swarm will weigh from 4 lbs. to 5 lbs.—*i.e.* it will contain from 20,000 to 25,000 bees.

dies and the bees are not "knocked up" and informed of their master's decease, the death of the bees will surely follow. The orthodox method of procedure is to knock gently upon the hive, addressing the bees thus:

> "Wake, Brownie! wake!
> Your old master's dead,
> And a new one you must take."

The words vary a little with the locality, but the sentiment they convey remains the same. It is difficult to account for this curious superstition. Probably it is the direct outcome of traditions which credit the bees with the possession of very great intelligence. In the foregoing pages we have been able to glean something of what this intelligence is, and how complex is the organisation that governs the work of the bee-hive.

FIG. 17.—THE GREAT TIT *(PARUS MAJOR).*

This bird has acquired an unenviable notoriety as a slayer of bees. The truth is that, in common with its relatives, P. cæruleus, P. ater, and P. palustris, it may occasionally devour a dead bee; it rarely, if ever, attacks a live one.

THE WIZARD ELECTRICITY.—VII.

ELECTRICITY AS A MOTIVE POWER.

BY FRANK C. WEEDON.

A MAN working in London can saw wood in Birmingham!

It seems absurd on the face of it, yet it is an actual possibility. Let us inquire how it can be done. We have already considered the dynamo-electric machine, and we have seen that an electric current is generated when the armature is made to revolve. But if we connect the terminals to some source of electricity so that, instead of taking current out, we lead it into the machine, we shall find that the armature will begin to rotate—so that the action of the machine is reversible. When we supply mechanical energy and obtain electricity, we call the machine a *dynamo;* but when we supply electricity and receive mechanical power, the same machine is known as a *motor*. Suppose we have two such machines connected by two conductors, so that there is a complete electric circuit. If the armature of either machine is caused to rotate, it will generate an electric current, which, flowing into the second machine, will set in motion the second armature. Thus it comes about that, with the aid of a dynamo and motor, the man working in London can do work in Birmingham. By means of a treadle or hand-wheel he can drive a dynamo in London, from which conductors convey current to a motor in Birmingham. The spindle of the motor armature may be connected with a circular saw by a driving belt, and in this manner the task may be completed.

We see in this illustration one great advantage offered by the electric current. Energy supplied in one place can be utilised in another. It is probable that this fact will bring about more economic and social changes than any other application of scientific discovery.

In the first place, much energy that is now running to waste will be made available. It is estimated that over three million horse-power in the United Kingdom alone might be obtained from the running water in rivers and cascades; while the energy of the falling water at Niagara is stated to be as much as could be obtained from all the men in the world working ten hours a day. Windmills also might be made to supply immense power at a cheap rate. It has been difficult to make use of such sources of energy hitherto, because it often happens that the place where the power can be obtained is not suitable for the fixing of machinery.

The top of a hill might be an excellent site for a windmill, so far as wind-power is concerned, but to convey the materials and products up and down steep roads would involve much expense. Waterfalls, too, are often in very inaccessible places, among hills and mountains; and there are many spots where water-mills would have been established but for the great cost of the necessary foundations in the soft, wet soil.

These difficulties are being overcome by the use of dynamo and motor. Thus the mountain waterfall is made to drive a turbine, which works a dynamo (as in Fig. 1) erected at the foot of the waterfall. The current which is generated is led by conductors to supply light where it is wanted, and motive-power to machinery, which may be placed at any convenient spot.

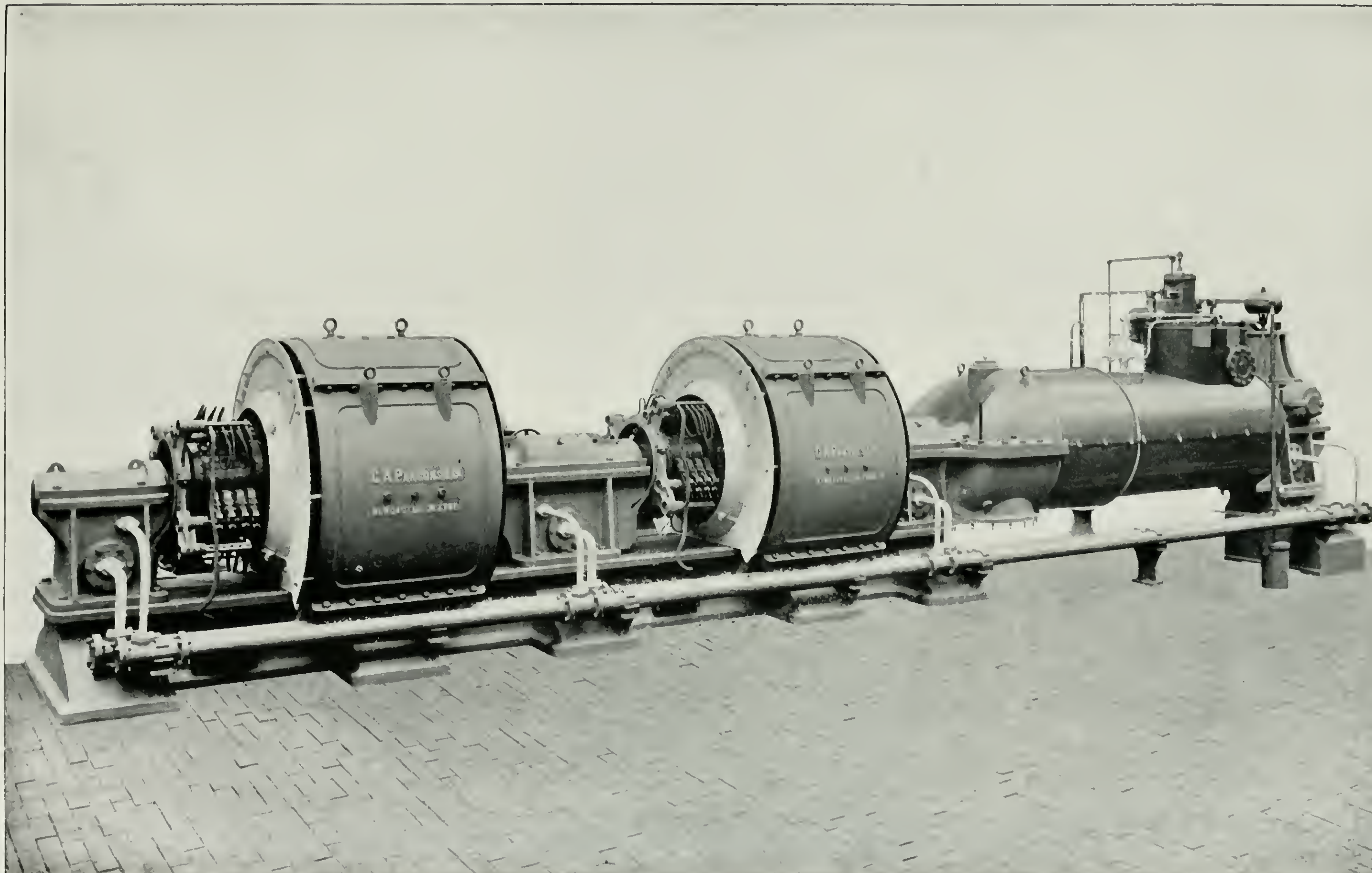


Photo supplied by Messrs. Parsons & Co., Newcastle-on-Tyne.

FIG. 1. A WORKING TURBINE DRIVING A DYNAMO.

In this way, part of the enormous available force at Niagara is being utilised, and people in other countries are following the lead of the enterprising Americans. In France an important undertaking of this kind has been completed in the department of Aude. The falls of the River Aude, at St. George's (328 feet), are used to drive turbines, and so to operate dynamos. The current produced is transformed up to 20,000 volts, and at this great pressure is conveyed to villages and factories as far distant as eighty miles.

coal would be infinitely less. In any case it seems probable that before long the country will be divided into districts, each with its central station supplying electricity as generally as water and gas are distributed already.

To business men the advantages would be many and great. In an engineering shop, for instance, supplied with steam-power, the machine tools are run by belting, driven by rotating steel shafts. There is a good deal of inconvenience as well as danger attending the use of shafts

Photo: Cassell & Co., Ltd.

FIG. 2.—ELECTRIC TRAIN ON CITY AND SOUTH LONDON RAILWAY.

The principle of conveying energy from one place to another along electric conductors may have another important application in the near future. At present we convey "bottled up" energy in coals from the pit to distant parts of the country, burning the coal to supply energy where it is required. It seems possible that the coal might be burnt at the pit's mouth to work steam-engines, which would drive dynamos and supply electric current. This current could be conveyed by well insulated cables, and supplied to consumers instead of coals. There would be losses, due to leakage and to heating of the cables, but the noise, dirt, and smoke attending the burning of

and belting, and often a considerable waste of power. If several machines are run from the same engine, it is difficult to provide work for them all in equal quantities. Accordingly, it happens that some are kept at work while others are still, and the same engine and fireman must be kept going as when all the machines are in motion. But if electrically driven machines are used, these objections do not apply. The central dynamos will supply the current for the whole of the plant. Each machine can have its own motor, which only consumes current when working, and even then only in proportion to the load. When some of the machines are at a standstill and the dynamo is

yielding more power than the working machines require, the balance of electrical energy can be stored up in accumulators, or used to provide electric light. In this way it happens that the economy of electrically driven machinery is sometimes startling. Recently an emergency job was sent to an engineering firm late on a Saturday afternoon, when the machines were shut down and the men had gone home. To start a steam-engine to drive the necessary machine tools would have cost about *ten shillings*, but by the use of a motor driven by electricity the cost was reduced to *twopence*.

Photo: Cassell & Co., Ltd.

FIG. 3.—PASSENGERS LEAVING ELECTRIC TRAIN (CENTRAL LONDON RAILWAY) AT THE BANK STATION.

The great ease with which electrical power can be distributed makes its use especially valuable in mining. Electrically driven picks, drills, and coal-cutters may take the place of the old-fashioned hand tools, and the materials may be conveyed to the surface by electric trams and elevators. What a contrast to the days when trucks were dragged by women to the pit's mouth along the dark and dirty tunnels of a coal-mine!

Since it is possible to generate large supplies of electrical force at a central station and to distribute the power without undue loss to an unlimited number of points in the surrounding neighbourhood, it may happen that electricity will be the greatest social reformer of the age. In the days of the hand-looms every weaver worked in his own home, but when steam power was applied all the looms had to be arranged near the engine, because the power could only be conveyed a short distance by means of belts and shafts. The modern factory and factory town was the result—built often, for economy of coal, in a place not very conducive to the health of the workers. There is much work that could be done on single machines worked by small motors. These could be fixed in separate dwellings at a reasonable cost, current could be laid on from a central station, and the operatives could enjoy the healthier country life of their grandfathers.

It has been shown that the economical working of machinery by electric power depends partly on the fact that the energy can be stored in storage cells or accumulators. A simple experiment will explain how this is done. Put some dilute sulphuric acid into a jar, and into the acid put two plates of clean lead. Each piece of lead should be connected by a length of copper wire with the terminals of a source of electricity. If the two pieces of

lead are allowed to touch, they complete an ordinary electric circuit, and the current flows in the usual way. But if the plates in the acid do not touch, it will be ob-

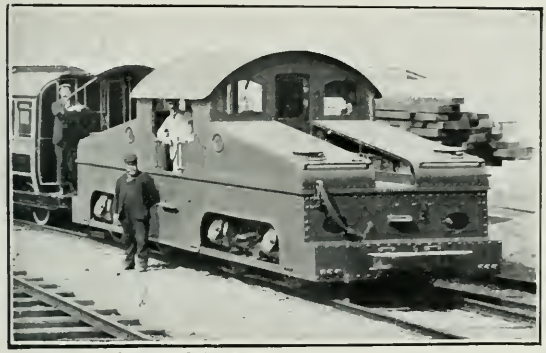


Photo: Cassell & Co., Ltd

FIG. 4.—ELECTRIC ENGINE, CENTRAL LONDON RAILWAY.

served that a current flows, and in crossing the liquid gives rise to remarkable effects. Bubbles will be seen rising in the liquid, and if these are collected they will prove to be hydrogen gas. If we examine the plates after a time, we shall find that the plate by which the current leaves the acid bath is quite clean, but the other is coated with a rich brown deposit, which chemical analysis proves to be an oxide or rust of lead. The most important part of the experiment is next to come. If we disconnect the wires from the source of current and simply join them together, we shall find that the lead plates in the acid form practically a cell supplying a current which flows in the opposite direction to that with which we started. At the same time the oxide of lead on the positive plate dissolves, and when it has disappeared the current ceases.

The two lead plates and the jar of acid constitute an accumulator or storage cell. Chemists say that these cells, strictly speaking, do not store *electricity*, but *chemical energy*. Nevertheless, the practical person will continue to speak of storing electricity, because he finds that he can put a charge into such a cell and take it out again. It may well be that *chemical energy* and *electrical energy* are really one and the same thing.

Modern accumulators are not made as described above. It is found that the capacity or power to store energy depends on the extent of the surface of the plates, and consequently in place of the smooth sheet of lead we now use leaden "grids," which may be regarded as plates with many holes in them. Further, to hasten the process of preparing the plates, the negative grids are filled with finely divided lead, and the positive grids are loaded with lead oxide. The action, however, is essentially the same as with the simple storage cell, consisting of two lead plates in a jar of sulphuric acid.

The discovery of the storage cell has brought about an important application of electrical power—viz. its use instead

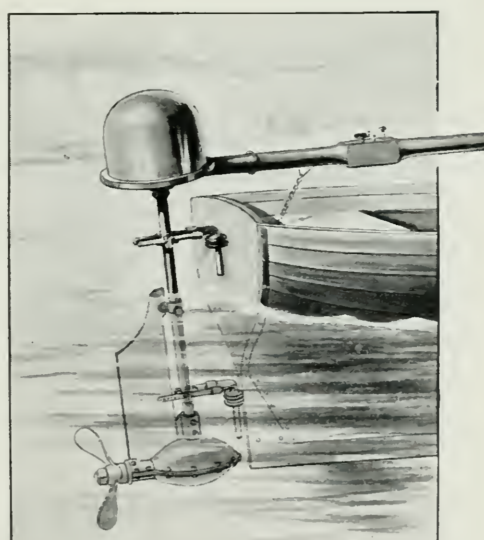


FIG. 5.—BOAT DRIVEN BY AN ELECTRIC PROPELLER.

of horses for vehicular traction. In principle this is a simple matter. If we place in a carriage a motor and a storage battery, we can maintain the revolution of the

motor armature while the strength of the current lasts. If the revolving armature is connected by a band or chain with the wheels of the carriage, the vehicle may be propelled. There are many difficulties,

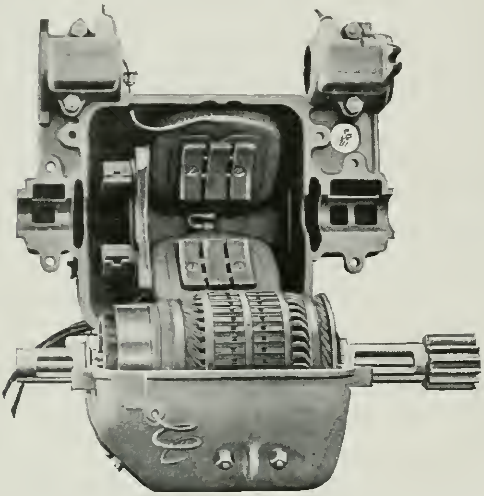


FIG. 6.—ELECTRIC TRAMWAY MOTOR, WITH UPPER HALF OF FRAME RAISED.

however, to be overcome before a thoroughly good electrical motor carriage is constructed. The accumulators, containing, as we have seen, lead plates, are very heavy. Then they will only take a limited charge, according to their capacity, so that re-charging is a necessity. It is found also that the storage cells deteriorate unless constantly used. Further, the plates are not improved by the jolting of the carriage over rough roads, and if a piece of the paste is caused to fall between two dissimilar plates so as to short-circuit them, the cell will be badly injured, and the charge lost.

Notwithstanding these difficulties, really serviceable electric carriages can be obtained, and in comparison with other motor carriages they have much to recommend them. There is but little danger; the mechanism is very simple and thoroughly under control. There is no noise or objectionable odour, and practically no vibration. The speed can be varied with ease, and, to a small extent, the energy which would be wasted ordinarily in running down hill can be stored up in the accumulators by running the motors as dynamos.

In London these carriages are a distinct success, owing to the enterprise of the City and Suburban Electric Carriage Company. Their ordinary four-wheeled carriage is fitted with two motors, one to each hind wheel. Each motor is of $2\frac{1}{2}$ horse-power, and drives by toothed gearing. The carriage will run forty miles without re-charging on a good level road at a speed of twelve miles per hour. A special carriage—the touring phaeton—will run 100 miles at thirteen miles per hour with one charge. The Post Office authorities have tried, with satisfaction, the capabilities of electrically driven vans, and many private firms have adopted this form of horseless vehicle. In America large "freight vans," as they are called, are becoming popular. The utility of this kind of motor-car depends upon the efficiency and durability of the accumulator, and, in spite of improvements that have been made, we have yet to look for a really satisfactory storage-cell.

Many of the objections to the use of accumulators do not apply when they are

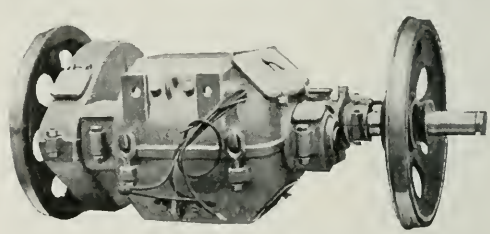


FIG. 7.—ELECTRIC TRAMWAY MOTOR, COMPLETE, WITH WHEELS: FRONT VIEW.

used to propel pleasure-boats and launches. The jolting of land carriages especially is absent, and consequently one serious source of trouble is not met with. To many people the fussy, smoky, steam launch is quite out of place in a beautiful reach of the river on a quiet summer day,

but the electric launch glides silently along, unobtrusively, and does not detract from the general tranquillity.

An ordinary river skiff can easily be converted into a miniature electric launch by means of the apparatus shown in the illustration (Fig. 5). Storage cells are placed in the bottom of the boat, and these are connected by wires with a small motor beneath the dome-shaped cover. This works a small screw, by which the boat can be propelled at any rate up to six miles an hour.

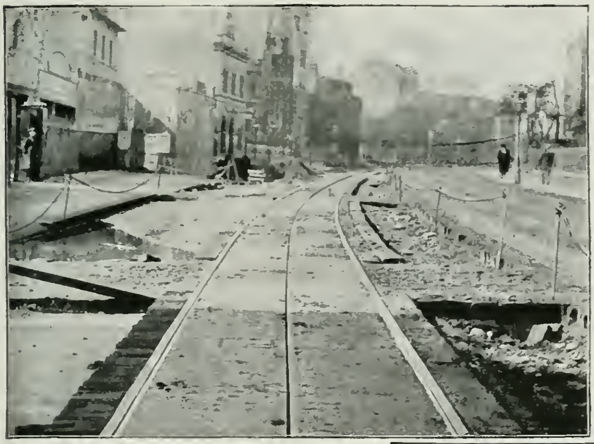


FIG. 8.—LAYING METALS FOR ELECTRIC CARS.

The satisfactory employment of accumulator-driven motors on rivers would suggest that accumulators could be turned to account for trams. They are extensively used in this way, but never with results which are altogether satisfactory. In some cases they have been adopted and then abandoned as too expensive. In Italy they are used in place of steam for trains as well as trams, but where dividends are looked for accumulators are not considered economical. Other methods of supplying current to the motors have, however, been adopted with such great success that electrical traction on tram-lines and railways is to-day by far the most important part of the use of electricity as a motive-power.

Electric traction has proved its superiority to horse traction for tramwork. Its cost is about one-half, and the speed and comfort of the cars are greater. From what has been already said it is clear that each car must have one or more motors, and that to these motors must be supplied electric current. We will consider first the motor and then the supplying of the electric current.

A tramway motor is shown in the illustrations (Figs. 6 and 7). In principle a tram motor is like any other motor, but, because of the use it is put to, its construction has marked peculiarities. In the first place, fixed as it is to the axle of the car, it must be dust- and water-tight. Then it must be contained within the three dimensions of about thirty inches, and produce great power in proportion to its size and weight. No other engine weighing, as this does, less than one ton will yield an output of twenty-five to fifty horse-power, wasting but one-tenth of the energy supplied to it.

FIG. 9.—LAYING METALS FOR ELECTRIC CARS.

Then, again, the frequent starting and stopping of the car subjects the motors to great variations of load, so that the machine must be compact, light, powerful, and economical. The current which drives the motors is, unless accumulators are used, generated at a central station, and conveyed to the motor in such a manner that the latter may be continuously fed as the car moves along.

The most popular method of supplying this current is by means of an overhead wire running from the generator (Fig. 10). An arm from the top of the car is held in position by a spring, so that a wheel or "trolley" at its upper end remains in contact with the current-carrying wire. From the trolley, conducting wire leads the current to the motor beneath the car. There must be a complete electrical circuit to and from the central station dynamo. and the return conductor is the metal track on which the car runs (Figs. 8 and 9).

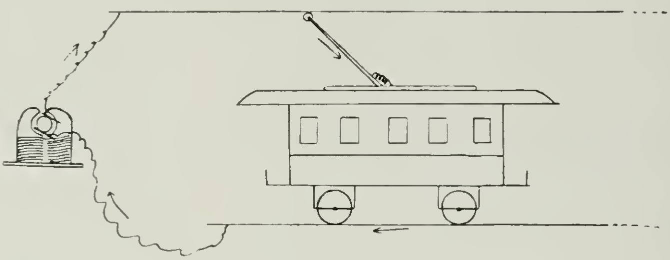


FIG. 10.—DIAGRAM SHOWING THE OVERHEAD TROLLEY SYSTEM FOR ELECTRIC CARS.

The arrows show the passage of the current from the dynamo on the left. Note the trolley arm, commonly spoken of as a "fishing rod."

In actual practice the working is not so simple as here described. If the tramway extended a considerable distance, it would be found that when the car was a long way from the generator the current obtainable would be insufficient. Accordingly, the track is divided into sections, and to these sections run separate cables ("feeders") from the generator. These sections are insulated from each other, so that a breakdown on one section does not interfere with the activity of the rest of the line. It is necessary that the portions of the metal track in each section should be "bonded" together so as to form a continuous conductor; otherwise the current would "go to earth," and, should there happen to be an iron water- or gas-pipe near, would eat the latter away.

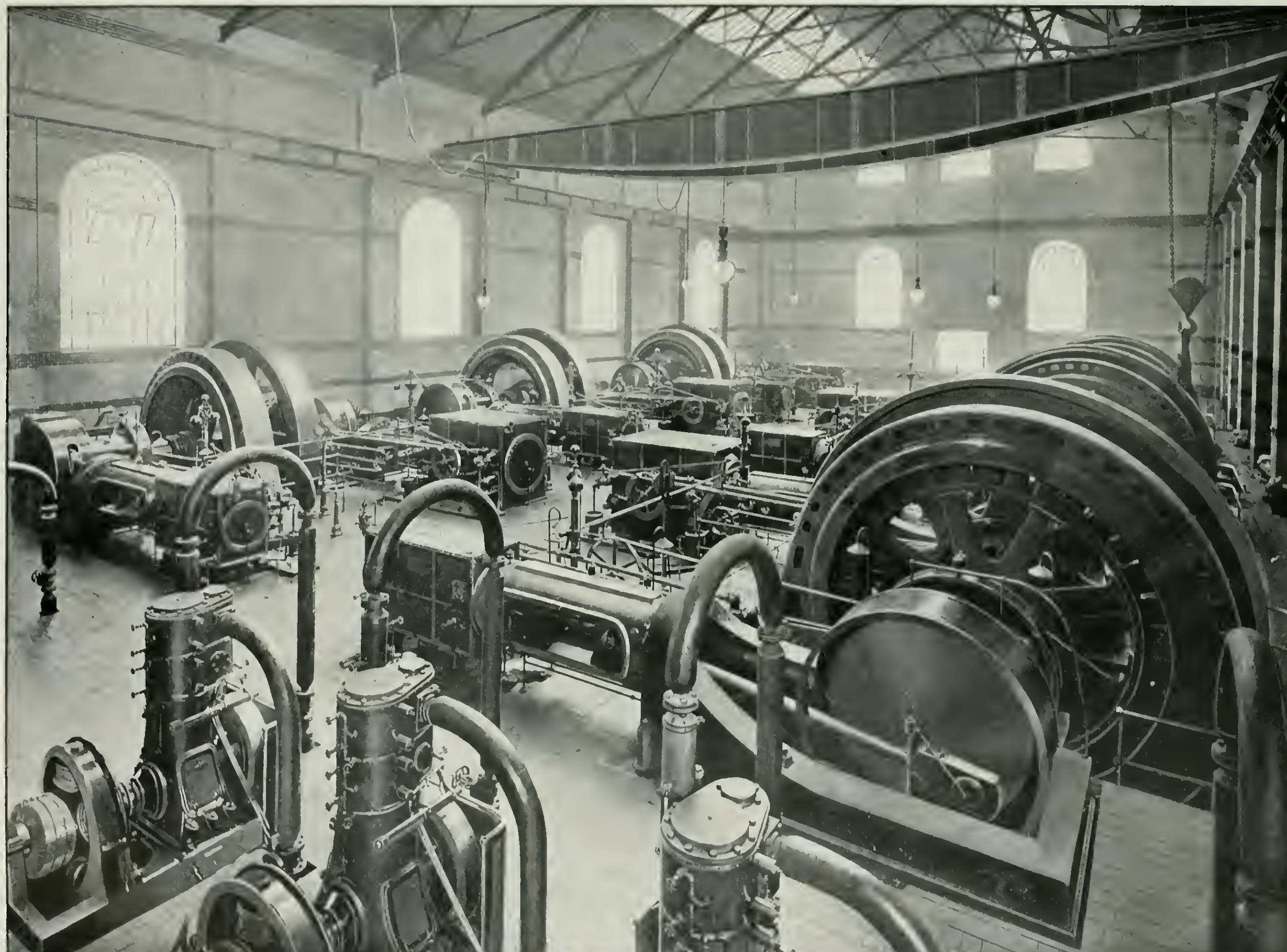
This overhead trolley supply and track return system is by far the most important method of working electric tramways. In America there are more than 20,000 miles of tramways using the overhead wires.

Many persons, however, consider that the wires and supporting posts are a disfigurement to rural roads, and a serious menace in crowded urban streets. Many have been the inventions designed to supplant the overhead method of conveying the current, but only one other system is a really serious rival.

This—the open conduit system—has been adopted by the London County Council.

Along the track, generally midway between the rails, a continuous tunnel is constructed of concrete, containing at regular intervals iron supports for the conductors, which are fixed on insulating material. Both the "flow" and "return" conductors are thus arranged, and, in consequence, there is small likelihood of destroying iron water- or gas-pipes. A narrow opening extends along the whole length of the tunnel or conduit, and the conductors run immediately beneath this opening, and about six inches apart.

A "*plough*" projects into the opening from beneath the car and completes the electric circuit through the motors. The "plough" is a hard steel plate carrying two cast-iron rubbing blocks, one on each side. These blocks are pressed outwards



By permission of Messrs. Thomson, Houston & Co.

FIG. 11.—POWER STATION OF THE CENTRAL LONDON RAILWAY.

by springs to touch the conductor bars, and are insulated from each other. At crossings this system offers exceptional difficulties which at present can hardly be said to be overcome. In Bournemouth both overhead and conduit systems are employed—the conduit within the borough and the overhead wire in the suburbs.

magnets, which switch on the main current through the car motors.

Where the track is private, as in the case of a railway, a simpler method is followed. The current is supplied to the motors by a third rail, placed, as a rule, between the track rails. One of the earliest electric railways in this country—Volk's electric railway at Brighton—was worked on this plan. This method has been adopted extensively in the Metropolitan district. The City and South London Railway (Fig. 2), the Waterloo and City Railway, and the Central London Railway—popularly known as "the Tube" (Figs. 3, 4, and 11)—are all worked on the third rail system.

FIG. 12.—ON THE KEW AND HAMMERSMITH LINE: THE OVERHEAD TROLLEY SYSTEM.

By permission of the London United Tramways Company.

Another system—the closed circuit—has been favourably reported on. The track is divided into short sections. insulated from each other, and feeders are supplied to each section. The track metals form the conductors, but each section only conveys a current while it is being traversed by a car. This is effected by an ingenious arrangement of metal plates or "buttons," which complete electric circuit from accumulators on the cars round electro-

Another system has been adopted on the Great Northern and City "Tube" which

connects Finsbury Park and Moorgate Street. The track has both positive and negative conductors, which are both insulated, and provide for the flow and return of the electric current. The advantages claimed for this—the third and fourth rail system—is, that there is no leakage of the electricity to earth, causing thereby corrosion of gas- and water-pipes by *electrolysis*, as happens when the third rail system is employed.

The illustration on this page is a reminder of the enormous progress made in electrical railways in recent years. The Lichterfelder railway was the first commercial electric railway constructed, and was laid down a little more than twenty years ago. To-day there are in America alone about *twenty-six thousand miles of electric railways*, requiring nearly 1,000,300 horse power for their operation. The total number of persons employed on these railways is about 140,000, and the wages paid to them amount to nearly £17,000,000 yearly.

Photo supplied by Messrs. Siemens, Schuckert and Werke.

FIG. 13.—CAR USED ON THE LICHTERFELDER TRAMWAY, BUILT IN 1881.

21

FORKED LIGHTNING.

HOW BUILDINGS ARE PROTECTED FROM LIGHTNING.

SINCE Benjamin Franklin showed that the lightning flash was but a discharge of atmospheric electricity, it has been studied by many meteorologists, and the conditions which bring it about are pretty well understood. To Franklin we owe the suggestion of the lightning conductor, and we cannot do better than quote his own words, more especially as they describe an attribute of the lightning rod not very generally known—namely, the power of its pointed head to dispel, in what is called the silent discharge, the charge of electricity which otherwise might have a disruptive effect. His words are: "May not this power of the points be of use to mankind, in preserving houses, churches, ships, etc., from the stroke of lightning, by directing us to fix on the highest parts of those edifices upright rods of iron made sharp as a needle, and gilt to prevent rusting, and from the foot of those rods a wire down the outside of the building to the ground, or round one of the shrouds of a ship, and down her side till it reaches the water? Would not these pointed rods probably draw the electric fire silently out of a cloud before it came nigh enough to strike, and thereby secure us from that most sudden and terrible mischief?"

There is the germ of the idea, and we shall now see how it is realised in modern practice. But we need not consider the question of ship protection, for the general adoption of wire rigging and the use of iron instead of wood in the construction of vessels render them almost immune from the danger of lightning stroke.

The first thing to be considered in arranging for the protection of any building against lightning is the metallic conductor which is to be provided to serve as the main channel for the electrical discharge. The self-same plan which was adopted in the first instance by Franklin has still, in the main, to be pursued. A continuous metal bar, or rod, is to be attached to the building so that it projects into the air above its highest part, and dips into the earth below its foundations. This rod must, above all things, be of sufficient capacity for the work which it is intended to perform; that is to say, it must be so thick that it would not offer any material resistance to the largest discharge of lightning that could in any circumstances be thrown upon it from the clouds. It must be of such ample dimensions that it would not even be heated to any great extent by such a discharge, for heat in such circumstances, it must be remembered, would imply the presence of resistance or obstruction, and the object of the contrivance is that the transmission shall be unimpeded and free; otherwise the rupture of the conducting material will follow—in other words, the rod will be destroyed. Franklin used iron for his rod, on account of its comparative cheapness; but copper is now very much more generally employed, for various reasons. It is more readily bent so as to be applied closely to all the irregularities of the building, it is less easily corroded by moist air, and it has a very much higher conducting capacity. Iron may be as effectively employed as copper; but, if this is done, the main stem of the rod must be six times as large as it would

need to be if it were of copper—that is to say, it must have six times the amount of metal in any given length. Beyond this it must also be examined after its erection from time to time, to make sure that its conducting capacity has not been diminished by the influence of corrosion. This is a point to which those responsible for the safety of large buildings should carefully attend.

The Lightning Rod Conference, which held its sittings in 1882, paid very great attention to the subject of capacity of conductors for the adequate protection of buildings, and they decided that the minimum size of the rod or tape employed should be represented by six ounces of copper to the foot run. This would mean in practice a copper tape $\frac{3}{4}$ inch in width and $\frac{1}{8}$ inch thick. But, as the electrical resistance of a conductor must vary with its length, it is customary to increase the sectional area of the copper for high buildings. The following sizes are generally employed:

For conductors less than 80 feet long	$\frac{3}{4}$ inch by $\frac{1}{8}$ inch.
For conductors over 80 feet and under 120 feet ...	1 inch by $\frac{1}{8}$ inch.
For conductors over 120 feet and under 180 feet ...	$1\frac{1}{4}$ inches by $\frac{1}{8}$ inch.
For conductors over 180 feet	$1\frac{1}{2}$ inches by $\frac{1}{8}$ inch.

Still thicker tapes than these are occasionally used, but, as a rule, in cases where exceptional durability is required rather than for any advantage in conductivity.

The strip, or bar, may be safely and advantageously attached directly to the masonry or brickwork of walls. No better plan can be pursued than to clasp a bent strip of copper round the conductor, and fix this to the wall by copper nails driven into the joints, as shown in Fig. 1. The exact form of the conductor, however, is not a matter of any real consequence, provided only that there be thickness enough of the metal. The strip is sometimes rolled up into the form of a hollow cylinder or pipe. It is sometimes moulded into the shape of a solid cylindrical rod, and it is very commonly replaced by a rope of copper wires twisted together. Fig. 2 represents the kind of copper wire rope which is most frequently employed, attached to the wall in a similar way to the flat conductor.

The clips which secure the conductor are fastened to the building by means of stout jagged copper nails, and it is usual to attach these clips at a distance from one another of not more than four feet. In the case of a building in course of erection provision should be made for the conductor by inserting between the bricks at regular intervals copper bolts, as shown in Fig. 3. The tape and its clips can then be readily secured to these by means of screw nuts. In the photograph the two bolts are shown lying on the topmost brick, and below we see the clip complete with the nuts secured to the bolt heads.

At one time it was thought necessary to insulate a lightning conductor, as a telegraph wire is insulated, by the provision of glass or earthenware supports which hold the rod a few inches away from the building to which it is attached. But they are worse than useless, for they interfere with one important function of a lightning conductor, which is to silently discharge the current of electricity which has been induced in the building by the atmospheric conditions. If the conductor is in perfect order, and has been fixed with a due regard to the metals in its neighbourhood, there will be no tendency for the discharge to leave the open path which the "rod" affords for the more difficult path offered by the materials of which the building is constructed.

The conductor, whatever its length, must be absolutely continuous from end to end. If under any circumstances

separate pieces have to be joined up in the length, these must overlap by clean metal surfaces some inches in extent, and be closely riveted or bound together in such a way that the intrusion of moisture

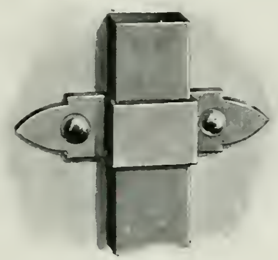


FIG. 1.—LIGHTNING ROD FASTENED TO A WALL BY A COPPER STRAP AND NAILS.

between the surfaces in contact shall be prevented, or the life of the "rod" will not be long. Wherever it can be done, the joints should be very carefully covered over by a coating of solder to prevent the corroding influence of moist air. But joints, as a general rule, are not required in the main stem of the conductor, because both ropes and strips, or, as these are technically termed, *tapes*, of copper are now manufactured of any length that is required. A rolled copper tape which is very flexible, and therefore very convenient both for transport and for application to irregular surfaces, is now being gradually introduced by electrical engineers, and is entirely deserving of general confidence.

When a copper conductor of this kind has been properly applied to the walls of a building, its efficacy as a protection in a large measure depends upon the fact that when a lightning-charged cloud hovers in the air a little distance above the top of the "rod" it becomes powerfully electrical, through the influence of induction, with a charge of an opposite kind to that in the cloud. And there is therefore a strong tendency for the charge in the cloud to pass into the "rod," and for the charge in the "rod" to issue to the cloud.

The importance of this matter of lightning protection is hardly realised by those who have paid but little attention to the subject, and who have, therefore, a very slight notion of the amount of damage done by lightning every year. Mr. Alfred Hands, who is one of the first authorities upon the subject, enumerates in a recent work on "Thunderstorms" a number of cases which he has selected from newspaper extracts published during the years 1899 and 1900. These comprise 600 disasters which occurred during those two years in Great Britain alone, and include loss of life as well as damage to property. He is of opinion that in England alone the monetary loss from this cause amounts to between £50,000 and £100,000 in every year. And he is corroborated by another expert, Mr. Killingworth Hedges, who, in a paper read before the British Association in 1901, referred to the terrible amount of damage caused every year by lightning, damage which he considered might be

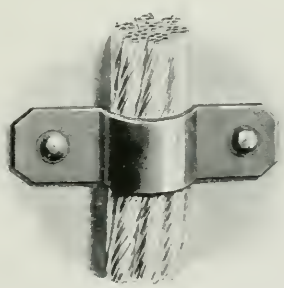


FIG. 2.—ROPE OF COPPER WIRE FREQUENTLY USED FOR LIGHTNING CONDUCTORS.

mainly prevented by the installation of proper lightning conductors. He made an assertion, which will come as a surprise to many, that not one church in ten in this country is furnished with a conductor, and he gave as a potent reason for the omission the fact that a vicar wishing to safeguard the building

under his care had usually to pay the cost out of his own pocket.

Loss of life and damage to property has also formed the subject of inquiry in other countries. Some short time ago the United States Weather Bureau published the results of an investigation which extended over eleven years, commencing with 1890, and this return showed that the average number of persons killed yearly by lightning stroke was no fewer than 377.

Of late years a very useful series of reports has been issued by the Lightning Research Committee, which was organised by the Royal Institute of British Architects and the Surveyors' Institution in 1901. These reports describe the action of lightning on buildings as recorded by numerous observers scattered about the country on behalf of the committee, and an important circumstance in connection with them is

Photo: T. C. Hepworth.

FIG. 3.—BRICK SHOWING STAYS AND FASTENINGS FOR LIGHTNING ROD.

that an asterisk is appended to those entries which include buildings fitted with one or more lightning conductors. The owners or occupiers of all buildings which may be struck by lightning are invited to send in reports to this committee, and if such reports are accompanied by photographs or sketches showing the damage done, so much the better. For the preparation of such reports the

FIG. 4.—LIGHTNING ROD WITH SEVERAL POINTS: AN AIGRETTE.

committee are prepared to pay any reasonable expenses. They are mostly interested in cases of damage where a lightning conductor has been already provided, as they specially wish to investigate the cause of the failure of such conductors to do the work expected of them. In this way a most valuable collection of information is being accumulated, and in process of time these notes as to the action of lightning on buildings which have been supposed to be efficiently protected will prove of the utmost service in pointing out the weak places in the armour. Two entries from one of these reports may be quoted in order to show the nature of the information afforded. They both refer to cases where buildings were struck although they were provided with lightning conductors.

"*July 25th, London.*—St. Anne's Church, Soho; during thunderstorm lead gas-pipe found to be perforated, and the gas ignited, causing slight fire."

"*July 22nd, Walsall, Staffs.*—Shire Oak Brewery chimney (70 feet high) struck, and upper bricks displaced.

Chimney fitted with copper tape conductor. Top part of conductor for about 12 feet down went yellow, as if it had been fused, and about a shovelful of loose earth was thrown out away from foot of conductor. Lightning seems to have struck far side of chimney, and then passed to conductor and to earth."

In every case a lightning conductor is so planned that it terminates above either in a point or in a cluster of points arranged in some such way as is represented in the accompanying illustrations (Figs. 4 and 5). Fig. 4 shows the form in most general use in England. Fig. 5 represents the very excellent modification that has been introduced by M. Callaud in France, in which sharp radiant spikes are fixed upon the upper surface of a flat ring of copper, with one long terminal point rising in the centre above. The main stem in each case is a copper rod about three-quarters of an inch in diameter, and so contrived that it can be firmly screwed into the upper end of the conductor.

The lower extremity of a lightning

FIG. 5.—MULTIPLE POINT LIGHTNING ROD: USED ON MANY BUILDINGS IN FRANCE.

conductor, where it passes into the earth, is even more important to the efficient action of the apparatus than the pointed summit which is projected in the air. As in the case of the rain-pipe which is prepared to protect a house from injury by wet, it would be of small consequence that the pipe itself were of ample dimensions for the passage of the rain if it were narrowed and obstructed at its outlet at the bottom; so is it also with the conductor which is provided for the safe transmission of the lightning. If there be not room enough for the pent-up downpour, whether it be water or electricity, to escape, there must be a mischievous overflow; and the overflow, if it be of electric fire, may obviously be attended with more disastrous results than if it were merely a deluge of water. Although the water and the electrical force are, in truth, quite different things, this comparison is by no means overstrained, for the earth is the great reservoir of both. Whatever amount of either is raised temporarily into the air must sooner or later flow back again to the ground, and, if conduits are provided for the conveyance of the flow, they must be so planned as to permit an unobstructed passage.

The outlet for the discharge of lightning from a conductor into the earth is, however, a matter of extended superficial space rather than of internal cavity, such as water would require. The transmission of the electrical discharge, on account of the expansive repulsion of the force, is accomplished mainly along the outside, or superficial, molecules of the conductor, rather than within. What is therefore required in providing the outlet into the earth is an amplified expansion of the mass. The conductor must be enlarged where it comes into communication with the ground. It is not enough, as is too commonly conceived, that the rod shall be thrust a few inches into the earth. It must be carried a considerable distance into the soil, and must be placed everywhere in the most intimate connection with it. This must on no account be lost sight of. A lightning rod with an insufficient earth contact is not only useless,

but dangerous in an extreme degree, and the more ample its own dimensions above ground the more imminent the danger if there be an obstructed outlet beneath. It is not possible to insist too strongly upon this, because mistake or oversight in this particular is a more frequent source of injury by lightning than any other circumstance that is encountered. In nearly every case where damage has occurred to buildings that have had lightning conductors attached to them it has been found that the mischief can be traced to this cause—an overflow brought about by impeded outlet to the earth. When a lightning rod of ample capacity and of sufficient earth outlet receives a stroke of lightning, the discharge passes down it in the form of a gentle stream which has not the slightest inclination to burst out anywhere. A living person might stand close to the rod at the time of the discharge without incurring any risk. But if the same stroke were falling upon a rod with insufficient outlet to the earth, being thereby impeded in its flow, it would pass haltingly along, and with a constant inclination to burst out laterally by the way, so that anyone standing in close proximity to the rod at the time of the discharge would be in imminent danger of receiving some portion of it through himself. As an absolute matter of fact, when a stroke of lightning passes to the earth through a building furnished with a conductor, it does not quite confine itself to the open path. It avails itself of all the substances that lie in the direction of its track, but it distributes itself amongst them in proportion to the facility with which it can make its way. Very much the largest part goes by the easiest route. With a large conductor of ample earth contact very nearly the whole of the discharge passes harmlessly through its easy line, so that only a very minute, and quite unimportant, portion is left to traverse the more difficult route.

In the Hôtel de Ville at Brussels —which is, perhaps, one of the best examples of lightning defence applied to a public building upon a large scale —no less than 426 points have been provided. The main branches of the conductor are carried along all the ridges of the roof, and shoot up as a complete forest of tufted spikes from all the pinnacles and towers. The chief front of the building has a pinnacled turret and spire rising 297 feet above the ground, and bearing at the top a gilt statue of St. Michael flourishing his sword over the prostrate dragon. The point of this sword serves as a very appropriate termination to the system of conductors. But it is not relied upon alone. In order to make assurance doubly sure, the platform upon which this figure stands is surrounded by a vast chevaux-de-frise of forty-eight spikes, radiating out to all quarters of the sky in a circle sixteen feet in diameter. The statue is pivoted upon a stout central bar of iron, which rises out of a lead- and copper-covered cupola, and this metallic mass is closely connected with the highest range of the coronet of spikes.

Eight iron rods run down from this lofty spire, and are joined below by numerous other rods that descend from the subordinate pinnacles and spires, and these rods are all at last collected into one metallic mass in the inner court about three feet from the ground, by being plunged into a square iron box quite filled with zinc, that has been poured in round the rods in a molten state. Three times as many rods, distributed into three distinct bundles, then issue from the iron box beneath, to establish the connection with the earth, and of these one bundle passes down to an iron tank sunk into a water-filled well dug out beneath the foundations of the building. The second bundle is carried to the iron main of the water supply of the town ; and the third is continued on in a similar way to one of the

large iron mains of the gas supply. In this ingenious way not less than 300,000 square yards of earth contact have been secured for the lower termination of the system. In spite of these elaborate and costly arrangements, the building was struck by lightning in July, 1888, and set on fire owing to one of the conductors passing in dangerous proximity to some metal inside the building to which it was not connected.

It should be known that it is practicable to ascertain how far in any individual case sufficiency of capacity has been attained by testing the resistance which the system of conductors affords to a weak current of artificial electricity passed through it to the earth from a battery provided by the electrician for the purpose, although this requires a considerable amount of technical knowledge and skill in the operator to carry into effect. Such tests need also to be repeated from time to time to make sure that the channel of outlet into the earth is not becoming accidentally diminished or obstructed through the influence of corrosion.

In the memorandum of instructions which was issued by the French Academy of Sciences in 1823 it was laid down as a kind of law that every point of a lightning conductor efficiently protects a conical space which extends as far again round the centre of the base of the cone as the cone itself is high. It is now known that this proportion is not implicitly to be trusted to. (Sir Henry Preece has calculated that a lightning conductor of a given height above the surface of the ground will protect from the external action of electricity a conical space the radius of whose base is equal to the height of the rod, but whose side is hollowed in the form of a quadrantal arc.) The lightning conductor should

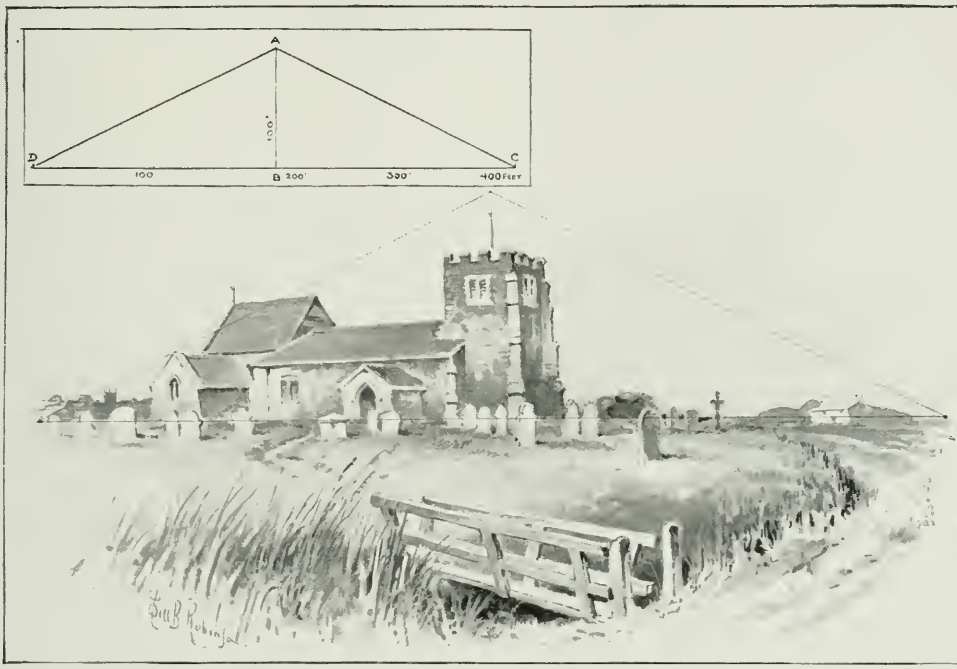


FIG. 6.—SHOWING SPACE PROTECTED BY A LIGHTNING ROD.
The church shown here is that of Mablethorpe, Lincoln, one of the many unprotected churches. Notice that one rod upon the tower would not be enough to protect the whole of the building.

be arranged so that no portion of the building presumed to be under its protection projects anywhere beyond the surface of such a cone, having a base four times as wide as the conductor itself is high, without an additional point being furnished to it, and placed in connection with the conductor. If the sketch in Fig. 6 be taken to represent a church with a lightning conductor A B upon its tower, whose terminal aigrette A is 100 feet above the ground, and the lines A C, A D, be conceived to mark out a cone whose base is 400 feet in diameter, then the gable on the left of the church would be beyond the area of protection, and it would be necessary that an additional point, or tuft of points, should be erected there, and connected with the main stem of the conductor. Any number of branches and points may be arranged upon the same general system where large buildings are concerned, as, indeed, is the case in the instance furnished by the Hôtel de Ville at Brussels.

There is one measure of precaution which must never be lost sight of in arranging any system of lightning conductors in towns. The rods must in no instance be carried anywhere near to small, soft-metal gas-pipes, or there will be imminent risk of the discharge escaping deviously to the gas-pipes, on account of the very large and free metallic communication with the earth which these invariably possess, melting them during its passage, and setting fire to the gas which escapes at the damaged place. Very numerous instances are on record in which the discharge has burst in this way from a conductor with small earth contact through six feet of solid masonry to get to a gas standard, with large earth communication, fixed on the inside of the wall immediately opposite to the conductor. The obvious remedy for this danger, when for any reason a lightning conductor is required to pass near to a small flexible gas-pipe, is that the conductor should be itself carried down to one of the *large mains* of the gas supply. By adopting this plan it is clear that all risk would be effectually obviated, because a discharge of lightning would not under such circumstances need to strike across to the gas-pipe to get to the earth communication of the main, having already its own connection established with that same earth contact by a nearer and easier route.

Fig. 7 is from a curious photograph of the Palace Pier, Brighton, which was taken at night. Pictures similar to this, and showing the same irregular lines of light proceeding in all directions from the electric lamps, were taken at Dover a short time ago, and gave rise to much discussion as to the cause of the phenomenon. As these pictures were taken during a thunderstorm, it was at once suggested that lightning had something to do with the strange appearances. An eminent scientist took pains to suggest one or two plausible theories, in support of which he pointed out that the lamps stood on iron standards, and that an electric main was lying beneath the roadway, which seemed to attract these side currents of luminosity from the posts. Then someone succeeded in obtaining similar pictures when no lightning was about, and the effects were finally traced to their true cause. In taking photographs at night—which has only become possible since the introduction of the gelatine dry plate—it is usual to leave the camera with its lens uncapped for a period which may vary from a minute or two to half an hour or more, the longer time being required when there are many subdued lights in the picture which it is desired to secure. In the example before us the electric lamps would be strong enough to make an almost instantaneous impression upon the plate, but the exposure would be continued with

a view to obtaining some record of the minor lights, reflections upon the sea, details of buildings, and so on. The operator who took the picture had neglected to cap the lens of his camera before moving the instrument from its stand, and the act of moving it caused all these streaks of light to appear upon the negative as soon as it was developed. It will be noted that the sinuous forms are exactly duplicated at each lamp, and that their magnitude is exactly the same, although some of the lamps are near and some far off. This picture should teach us that it is wise not to jump to hasty conclusions.

FIG. 7.—PALACE PIER, BRIGHTON, PHOTOGRAPHED AT NIGHT.
The curious streaks of light in this picture were at first erroneously ascribed to electrical agency. (*See page 398*)

SCIENTIFIC DECEPTIONS.

By WILLIAM ACKROYD, F.I.C.

DECEPTION by means of scientific experiment now serves only the two ends of instruction and amusement. The person who places one hand in hot water and the other in cold, and then, after a little while, dips both in the same basin of lukewarm water alternately, finds that the lukewarm water appears cold to the warmed hand and hot to the cooled hand. He is entirely deceived in his estimation of the temperature, but profits by the lesson thus learnt of the fallibility of one of his senses. In early times, however, deception by means of scientific experiment served only one purpose: it was a powerful instrument employed by the rulers to awe the people, and, to this end, prince, priest, and sage were leagued together to impose on the masses, who at times could not be impressed unless by some appeal to what they, in their ignorance, considered to be supernatural. In some of the ancient temples votaries were occasionally treated to a sight of the gods, probably raised by optical means, and the oracular responses and weird voices which they likewise heard were due, without doubt, to scientific contrivances. The means then employed would seldom deceive people now, accustomed as we are to optical and acoustical wonders; but in a harmless way one may still practise devices which throw the judgment entirely at fault, no matter how educated one may be. The uninformed may be readily deceived on matters of observation alone where others would suffer no deception at all, as will be apparent in the following example.

It is easy to see that the juggler who keeps three or four balls tossing up in the air manages the feat through his quickness of eye and dexterity of hand. The trick, however, becomes inexplicable to some when performed by an acrobat standing on the back of a horse swiftly running round the arena of a circus (Fig. 1). Why do not the balls fall behind the performer? And this entertainer of the general public would, in all probability, be unable to assign the correct reason, although perfectly familiar with the truth of the fact. It is the same difficulty which leads a landsman to declare that, if a weight were allowed to fall from the top of the mizzenmast when a ship is in full motion, it would drop into the sea. When told that such a falling weight would land at the foot of the mast, he is incredulous until some sailor begins to relate his experience of how a marling-spike, a grease-can, or some other body, having been slipped from aloft by a clumsy shipmate, fell, much to his alarm, close to where he was standing, at a point directly underneath, although the vessel was at full speed. He cannot perceive that such ought to be the case until he has learnt the first law of motion in mechanics, viz. that every substance, if at rest, will remain at rest for ever, or, if in motion, will move on for ever in a straight line, unless some force being applied to it disturbs its state of rest, or alters or stops its motion in a straight path. The balls which the juggler has in his hands while his steed is careering round, and the weight at the top of the mast of the progressing vessel, possess respectively the same motion as that of the horse and that of

the ship. And if, so far as they are individually concerned, there were no force like gravity pulling them earthwards, upon removing their means of support, they would go on until the resistance of the air stopped them.

A rapid succession of inanimate pictures in the cinematograph gives one the impression of moving life-like forms.* In the study of other optical phenomena, one comes across many cases of deception which would lead the uninitiated to declare that they saw something more than or different from what really exists. With a single eye even one may see an object apparently double by the following simple device. Make two pin-holes in a piece of card-board at a distance from each other less than the diameter of the pupil, and hold a small object, like the head of a pin, not far from the eye, and view it through the two pin-holes. Two images of the head of the pin are seen, and yet there is only one pin-head. It is apparent, however, that the rays of light reflected from the pin-head through the holes into the eye are split into two minute pencils which are cast on to the retina to produce two separate images. The deception is therefore caused by the two pin-holes in the cardboard.

The advertising genius, racking his

FIG. I.—JUGGLER ON HORSEBACK TOSSING BALLS.

This illustrates the fact that the balls, in addition to the up and down movement, are travelling at the same rate and in the same direction as the horse and juggler.

* CASSELL'S POPULAR SCIENCE, Vol. I., p. 243.

brain for some device for taking the eye and retaining the attention, has occasionally hit on ways which are interesting from our present point of view. A harmless deception, which he often practises, is to have a large poster, the words of which are interspersed with others of much larger type, and which are, of course, easily read at a distance, while the words represented by the small type are indistinct. The words with large letters have been so chosen that when read they form a sensational announcement. Thus you may read that there is "£500 REWARD OFFERED FOR THE CAPTURE OF A POISONER," and, upon going close up to the bill to learn full particulars, find that it is only a pill vendor's advertisement; or you may read at a distance that "A BLACK MAN MAY BE MADE WHITE FOR NOTHING," and find upon a nearer approach that it is simply an announcement of the advantages to be derived from the use of somebody's blacking. This is a sample of the style of thing:

Mr. A. has the honour **TO** announce that he has just received a fine assortment of articles from the Metropolis, **ALL** of the best quality. The firms from **WHOM** they were bought are famous for the durability of their goods, and **IT** need hardly be said that our customers **MAY** feel no **CONCERN** on this head, as the wear of their last purchases will have fully proved their trustworthiness.

This announcement, seen from a distance, would appear to read "TO ALL WHOM IT MAY CONCERN," while upon closer inspection it would be at once observed that it was only a draper's advertisement. The ease with which a person sees a thing depends, of course, upon its size and distance. A particular letter, for example, has to cover a certain area of each retina in order that it may be distinctly discerned; and, as the image of any given thing becomes less and less in a definite ratio the farther the observing eye is away from it, there plainly is a limiting distance at which any particular size of type can be distinctly made out.

Marriotte's experiment, which illustrates the fatigue of the eye upon gazing at bright colours, and the subsequent production of complementary spectral images, has likewise been employed in a slightly modified form for advertising purposes. Thus you are requested to look at the name of the advertiser in white letters on a red ground for a minute, and then to transfer the gaze to a blank white space. This white space now appears of a bluish-green tint, and the name appears on it in red characters. If a small square hole be cut in a red wafer, and this be pasted on to a sheet of white paper, we shall find on repeating the foregoing experiment that the spectral image obtained after transferring the gaze from the red wafer, with its central white square, to a sheet of white paper, is a patch of bluish-green with a square of red in it corresponding to the square of white in the wafer. Hence, when a bright-coloured image is cast upon the retina it is surrounded by a complementary fringe, and therefore, when the gaze is transferred to a sheet of white paper, one sees, instead of the complementary fringe of which the eye has become tired, a fringe of the original colour which was stared at.

Next to the eye, not one of the five senses is so easily deceived as the ear. In fairness, however, to the ear, we must say that one kind of mistake anyone may make arises from no defect of the auditory organ, but from a physical peculiarity attending the transmission of sound under certain circumstances. A single echo may be produced in such a way that one has a difficulty in saying whence the sound has come. You are standing, let us say, not far from the side of a large building,

listening to the strains of a military band some distance off. The sound seems to come from the side of the building, and you look in that direction for the origin of the music when probably you ought to have looked in another direction altogether. The ear here makes no mistake, for the deception is caused by the reflection of sound from the side of the building, and is perfectly analogous to a simple case of reflection of light from a mirror. If you look into a mirror with a candle on one side of it, an image of the candle is seen which appears to be beyond the mirror, and one totally unacquainted with the peculiarities of reflected light would imagine the image beyond the mirror to be the source of light, until by observation and reasoning he had found out that the candle in front of it was the real source of the rays. So likewise in this case of the reflection of sound, the building acts like a mirror in reflecting the notes, and we look in the direction of the building for the musicians. A mistake of this sort, however, may arise from a totally different cause — namely, the inability of our ears to tell the direction in which a sound comes to us, when that sound has been produced in a particular position with regard to the two ears. I remember a curious case in point which happened in a place of worship. The assembled congregation had commenced singing the *Te Deum*, when the harmony was harshly broken in upon by a voice near to me, keeping neither time nor tune, and marring entirely the pleasurable effects of the music. Without moving my head, it appeared that the unfortunate singer was somewhere about a couple of pews behind. When we came to the *Jubilate* there was a recurrence of the annoyance, so, turning round to see whence the noise came, I suddenly became conscious that the unwelcome voice was not behind, but in front of me, and that the sounds emanated from an old lady in the very next pew, who had taken up a position just opposite me. It appeared highly improbable that reflection of the sound had anything to do with the phenomenon here; and the solution is to be found in the following experiment due to Cyon, and which may be very readily repeated.

Blindfold a person, and then make a clicking noise in various positions around his head. This may be readily done by taking a couple of pennies, and inserting a finger between them, while with the thumb and finger of the other hand they are pressed together (Fig. 2). Every time the finger is withdrawn the pennies come together and make a clicking noise. The blindfolded person cannot always tell whence the clicking noise comes. He is generally deceived when the pennies are in particular positions, and if the performer knows which are these positions he can show, for the amusement of all present, that his friend is woefully deceived. Imagine a plane cut through the chin, nose, and crown of the head so as to separate it into two symmetrical halves (Fig. 3). This plane is the *medial plane*, and all sounds produced in the medial plane are apt to deceive. If the sound be made behind the blindfolded person, he may think it is produced in front of him; and, if the sound emanate from a point in front, it may appear to be produced behind him. On either side of the medial plane the blindfolded person has not much difficulty in saying where the sound is produced.

In judging of the distance of a sounding body, we depend upon the intensity of the sound, taking as our standard for comparison the sound we know the same body to produce when nearer to us. Thus, when a horn is sounded, the blast we hear is far different from the faint reverberations which are reflected from distant hills. It will be perceived,

therefore, that in the matter of distance the ear may readily be deceived, and the impression of a full band at a distance will be conveyed to the mind by a hidden orchestra very near us playing softly. Ventriloquism is nothing more or less than the art of deceiving, by imitating as closely as possible every

FIG. 2.—CLICKING PENNIES.

variety of sound as it reaches the ear, *i.e.* regulating the different intensities so as to produce the idea of distance as well as of individuality of sound.

At the commencement we pointed out the deceptiveness of the sense of temperature, and what appears a more striking case of it still is shown in the following experiment :—Immerse the forefinger of one hand in water at 104° F., and then plunge the whole of the other hand into water with a temperature of 102° F. The latter, although two degrees cooler, will be judged to be the warmer of the two, from which it appears that the intensity of the sensation of temperature depends not only upon the relative degree of heat to which the parts are exposed, but also upon the extent of surface over which it is applied. From this cause a bath which is not uncomfortably warm when a few fingers are dipped in it appears scalding hot when the whole body is immersed. The sense of temperature is likewise entirely at fault when required to determine which is the warmer of two substances, say a piece of iron and a piece of wood, for if they both have the same temperature the iron will feel the hotter of the two, because of its being a much better conductor. A slight difference of temperature, however, between two substances of like nature is easily discerned; and we may here consider a simple but highly entertaining trick which is founded on this fact. The performer having placed his hat behind him, requests the people present to place in it three or four pennies. He shakes it up behind him, and then asks some person to take out a penny and closely examine it; then to pass it to the others for examination, the last one pitching it back into the hat again. The pennies are then reshaken up, and the performer now, placing one hand behind him, picks out the penny which has been examined, although throughout the whole operation he has never seen it. When the experiment has been done some two or three times successfully, all sorts of unlikely suggestions are made as to the way in which the feat has been performed, but very seldom the right one. Yet the trick is exceedingly simple. The people in handling the penny which was selected from the others make it warm. It is therefore easy to pick it out from the others when it has been pitched into the hat again. This sufficiently demonstrates the fact that at ordinary temperatures the sense of temperature as localised in the fingers is sufficiently acute to discriminate between several pieces of metal so as to tell which is the warmest. But for the extremes of hot and cold touch is thoroughly deceived, a piece of frozen mercury giving a burning sensation like a red-hot bar of metal.*

The touch which attains to such perfection in persons afflicted with blindness is readily deceived. This is shown forcibly by the experiment of Aristotle. Cross the index and middle fingers and run them over a marble placed on the

* CASSELL'S POPULAR SCIENCE, Vol. I., p. 227.

table with the eyes shut. Under such circumstances one has a difficulty in avoiding the belief that he is dealing with two marbles instead of one. The idea of roundness which has been obtained by a complex judgment, founded on the coalescence of several sensations, is here appealed to, but, the usual conditions being reversed, we draw a wrong conclusion. The sense of taste may likewise be confounded by altering the conditions under which the gustatory operation is always carried on. Thus, if the nostrils be held firmly, it is impossible to distinguish between the sensations produced by applyingan onion or an apple to the tongue.

Perhaps the most marvellous cases of deception the scientific man has to deal with are those which, as a rule, accompany some bodily ailment, and are produced without the immediate agency of any external stimuli. You may think you are listening to music, either vocal or instrumental, and follow the tune from beginning to end, while all the time there is no music being performed; you may fancy that you see the face of a friend who at the time may be dead or far away, and he appears to you with such reality that you call him by his name, but of course get no response—these are purely delusions of the senses, which are known as *subjective sensations*. An example or two may prove interesting. Sir John Herschell gives the following personal experience:—"I had been witnessing the demolition of a structure familiar to me from childhood, and with which many interesting associations were connected — a demolition not unattended with danger to the workmen employed, about whom I had felt very uncomfortable. It happened to me at the approach of evening, while, however, there was yet a pretty good light, to pass near the place where the day before it had stood, the path I had to follow leading beside it. Great was my amazement to see it as if still standing, projected against the dull sky. Being perfectly aware that it was a mere nervous impression, I walked on, keeping my eyes directed to it, and the perspective of the forms and disposition of the parts appeared to change with the change in the point of view, as they would have done if real." Sir David Brewster, an often quoted authority on this subject, gives remarkable examples of these spectral illusions. One of these, which we may here cite, affected the auditory organ. A certain Mrs. A., with whom he was well acquainted, was standing near the fire in the hall one afternoon in December in the year 1830, and on the point of going upstairs to dress, when she heard, as she thought, her husband's voice calling her by name "——, come here! come to me!" Upon going to the door where she thought he was, she found no person there. She returned to the fire, and again heard the

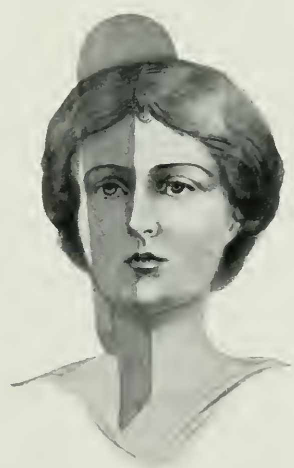


FIG. 3.—ILLUSTRATING THE TERM "MEDIAL PLANE."

same voice crying out distinctly and loudly: "——, come! come here!" whereupon she opened two other doors of the same room, without finding anyone. Once more she took her stand by the fireplace, and now the same voice appeared to call out in a loud, plaintive, and somewhat impatient tone, "——, come

to me—come! come away!" She cried out in response, "Where are you? I don't know where you are!" still imagining that he was somewhere in search of her. Receiving no answer, however, she went upstairs shortly after. Mr. A. returned home in about half an hour afterwards, and she was greatly surprised to learn that he was nowhere near the house at the time she supposed she had heard his voice. These are curious cases of illusion which do not affect everyone, but to those who are subject to them they come with great vividness, and it requires much strength of mind to dispel them. Not less startling are the sights a man sees who is labouring under *delirium tremens* brought on by excessive drinking, for before his unhealthy vision there arise up images of demons and all manner of loathsome beasts and reptiles which for the time being he regards as in actual existence. One person, informing the writer of his sufferings after a drinking bout of unusual length, said the "devils" took the form of a fish he was particularly fond of when he was in a sane condition, but which in his extreme state of nervous depression, while the delirium was on, caused him an infinitude of fright by surrounding him on all sides, open-mouthed, as if about to devour him, and staring at him stonily with their fishy eyes.

These apparitions are nearly as inexplicable as the phenomena of dreams, and the scientist contents himself with simply describing them as matters of natural fact, and framing somewhat unsatisfactory hypotheses to account for them. The examples I have given seem to favour Dr. Hibbert's hypothesis that spectral apparitions are nothing more than ideas, or the recollected images of the mind which, in certain states of bodily indisposition, have been rendered more vivid than actual impressions; and Sir David Brewster maintains that these recollected images or mental pictures have their place on the retinæ while the apparition lasts—in other words, that the mind's eye is the body's eye. His reasons admit of being placed before the reader very succinctly. Vision is of two kinds, *actual* and *mental*. "If we look at the façade of St. Paul's, and, without changing our position, call to mind the celebrated view of Mont Blanc from Lyons, the picture of the cathedral, though actually impressed upon the retina, is momentarily lost sight of by the mind, and during the instant the recollected image of the mountain, towering over the subjacent range, is distinctly seen, but in a tone of subdued colouring and in distinct outline. When the purpose of recall is answered it quickly disappears, and the picture of the cathedral again resumes the ascendency." In a healthy state of the mind and body, the relative intensity of these two classes of impressions is nicely adjusted; the *actual* picture is in the ascendency. But under certain conditions, as when one is suffering from indisposition, the *mental* picture is in the ascendent, giving rise to the apparitions we have spoken of, which, plainly, when viewed from this standpoint, are stripped of their terror. Herein we have the philosophy of the ghost which was a common phenomena in times when ignorance was more prevalent; now it appears to be relegated to the novel or the stage. (Fig. 4.)

These things we have spoken of, and others of a like nature, show how readily the senses may be deceived. We commonly declare with perfect confidence that we saw or heard or felt certain things, but the real truth is that we only judged that certain sensations of sight, hearing, and touch were caused by such-and-such things. When our judgment has played us false, as in the instances given, we have been without doubt victims to a kind of deception, which we have termed

scientific for the simple reason that it comes within the pale of science to analyse and ascertain all that it is possible to learn concerning these anomalous phenomena. The study is not only interesting but useful, for it may be helpful in enabling us to distinguish between the real and the unreal at times when this power of discrimination is of untold personal value.

FIG. 4.—"SPEAK! SPEAK!"
(From the picture by Sir J. E. Millais, Bart., P.R.A., in the National Gallery of British Art.)

THE CHEMISTRY OF THE BREAKFAST TABLE.

SITTING down to breakfast with no more luxurious accompaniment to our bread and butter than a cup of coffee and an egg or two, we will, for once, throw aside the morning paper, and endeavour to collect a few facts respecting the nature of the substances partaken of and the part they are likely to play in the body when consumed.

It is much to be regretted, in these days of scientific research, when scientific men meet with such appreciative audiences and scientific books enjoy a wide and ever increasing circulation, that there is still a vast amount of ignorance respecting the nature of what we eat and drink. We still select our food as we have done from time immemorial, simply from considerations of taste, without any reference to its nutritive value. A dish that does not contain any albumen or other flesh-forming material is eaten with as much avidity—provided it please the palate—as if its composition admirably fitted it to enable the body to perform its functions with unimpaired vigour and regularity.

There is no doubt that a goodly proportion of the "thousand ills that flesh is heir to" might successfully be guarded against by a wider dispersion amongst us of physiological knowledge, and a more general acquaintance with the chemistry of the human body so far as it relates to the appropriation and assimilation of food. Look around, and mark the general neglect of sanitary laws. Impure air, intemperance, and dissipation produce a long catalogue of disorders; but errors in diet are as effectual in shortening life as any of these causes, and are perhaps of more common occurrence. Intemperance and dissipation are not gentlemanly vices, but errors in diet are highly respectable, and sanctioned by the usages of the most fashionable society. Rich soups, highly seasoned dishes, and hot condiments are swallowed in defiance of the simplest dietetic laws. The poor stomach, constructed for simple fare in moderate quantities, is distended with a huge conglomerate of fish, fowl, flesh, and pastry, which the gastric juice cannot permeate, and digestion can only be effected by a disastrous expenditure of vital force. In youth and early manhood the elasticity of our constitution is such that a considerable amount of abuse can be borne without much apparent injury or loss of tone; but sooner or later there will come a revolution: the ill-used organs will rebel, and terrible will be the revenge they will take for the long-continued slavery and hardship to which they have been subjected.

Very little reasoning is required to show that there ought to be a close chemical relationship between the food eaten and the tissues which it is designed to build up. Every moment of our lives, disintegration, or the breaking up of minute fragments of the tissues, is taking place. Every organ, every vessel, and every muscle is perpetually losing part of its substance by the exercise of its own function. Even the brain is worn by every act of thought; and the effete or worn-out particles are carried away by the lungs, the skin, and the secretions. In order that renovation may go on side by side with disintegration, we eat; and unless our food be of the proper description and in proper quantity, the rate of wasting will be more rapid than that of repair, and emaciation will result.

The following table will show at a glance the chief food constituents :—

FOOD CONSTITUENTS

- Organic
  - Nitrogenous
    - *Albuminoids* (flesh-formers), including :—
      - Albumen (white of egg)
      - Gelatin (animal tissue)
      - Gluten (wheat)
      - Legumin (peas and beans)
      - Casein (milk)
    - *Amides.*
  - Non-Nitrogenous (heat-givers)
    - *Carbohydrates,* including :—
      - Starches
      - Gums
      - Sugars
      - Cellulose
      - Woody fibre
    - *Oils and Fats,* including :—
      - Stearin } solid
      - Palmitin } solid
      - Olein (liquid)
- Inorganic
  - *Water and Ash,* including :—
    - Phosphoric acid
    - Lime
    - Potash
    - Soda
    - Chlorine

If we take a food and submit it to the action of heat, it loses weight, which is due to water being driven off. That moisture is being driven off can be proved by placing, for two or three seconds, a cold watch-glass over the surface of the vessel in which the food is being heated. A coating of condensed moisture appears on the glass. If we now place the food, after depriving it of its moisture, in a furnace and heat for a considerable time, the organic portion will be combusted, or turned into gases, and so be driven off. A portion will remain behind that cannot be destroyed by heating, and this is the inorganic portion, otherwise known as the ash or mineral matter, consisting of salts, and resembling in appearance ordinary cigar ash.

Taking a fresh portion of the food, we can split up the organic portion into nitrogenous and non-nitrogenous substances. The nitrogenous portion consists chiefly of the *albuminoids*, though in some foods especially there will be an appreciable quantity of other nitrogenous bodies present, such as *amides*, which are distinguished from albuminoids by being soluble in water. "Amides" may be described as immature forms of albuminoids, into which they often change. They are not very valuable from a feeding point of view.

To demonstrate the presence of albuminoids, mix a little of the food with some soda-lime, and heat. Ammonia is then given off, and this shows the presence of nitrogen.

To determine the oil and fat, the food in treated with ether, which is a solvent for these substances and dissolves all traces of them which are present.

Carbohydrates, of which the chief are starch and sugar, are usually determined directly by alkaline copper solution.

The heat-givers are respiratory—that is, they promote the function of respiration by their excess of carbon. This element combines with the oxygen of the air in the lung-cells, and in so doing gives out that heat which preserves the temperature of the body at $98\frac{1}{2}°$ F. in all latitudes.

To take the chief organic substances in detail :—The importance of *starch* will be understood from the fact that it enters more largely than anything else into the composition of the food. It forms three-fourths of the weight of fine wheaten flour, and exists in still greater abundance in sago, arrowroot, tapioca, semolina, and cassava. Cereals seem to have been selected by man from the beginning of his history as his chief source of nourishment. All over the world, even amongst the most barbarous nations of Africa, we find grain of some kind cultivated for the purpose of bread-making. From the region of rye and barley,

extending to 70° north latitude, down to that of rice and maize within the torrid zone, we find the cereal grains instinctively regarded as constituting the great life-sustainer of the masses, while meat is simply an auxiliary. The bulk of that important article of diet, bread, is starch. It is prominent in seeds and fruits generally, as peas, beans, nuts of all kinds, apples, pears, and especially in those fruits—such as cassava, banana, and bread-fruit—which take the place of wheaten bread in countries of which they are natives. As starch is placed in the same subdivision of food constituents as fat, it must exert a similar physiological action. Starch, however, is worth very much less as a heat-giver than fat; in fact, $2\frac{1}{2}$ lb. of starch will, when combusted, only produce as much heat as is yielded by 1 lb. of fat.

Starch is not a flesh-former, and therefore the reader may be disposed to infer that the value placed upon grain, which

FIG. 1.—POTATO STARCH.

contains so much of it, is rather theoretical than substantial. It has already been stated that we require something besides the mere muscle-building elements to sustain all our functions; and it must be further laid down that *bulk* is another consideration of some importance in the selection of our food. The most nutritious

FIG. 2.—ARROWROOT STARCH.

substances in a highly concentrated form, and consequently in small bulk, used as food for a lengthened period, would fail to be attended with those beneficial results which might be anticipated from their chemical composition. To attempt to live altogether on extract of beef would be as hazardous as to endeavour to satisfy our thirst by taking our beverages boiled down to one-tenth of their original volume. To satisfy his appetite, a Hindoo must devour several pounds of rice daily; and an English farm labourer will eat an amount of bread with his cheese that would astonish an exquisite, who has simply heard of the "staff of life," but does not altogether see the logic of the phrase.

The amount of starch found in various vegetable articles of food varies from $2\frac{1}{2}$ oz. in a pound of potatoes to 12 oz. in the same amount of rice. Leaving out the potato, the nutritive value of these products may be taken in inverse ratio to the proportion of starch they contain. Thus, peas contain more flesh-forming material than barley, and barley more

than wheat, while rice is the least nutritious of the cereals. The studious housewife who peruses this article may say that she always looked upon rice puddings as very wholesome "things." To which we can only reply that so they are; but if you gave your children nothing but rice, they would require half a dozen such puddings a day, with a plentiful admixture of milk and eggs, if you wished them to have straight limbs and strong frames.

Pure starch may be obtained from flour by a very simple process. Tie up a tablespoonful of wheaten flour in a muslin bag, and repeatedly press it with the fingers in a basin of water. The water will be rendered milky, owing to the separation of starch. Continue the process till a fresh portion of water is no longer rendered turbid, and after subsidence the water can be poured off, and the starch dried and preserved. After the experiment with the flour, a glutinous adhesive substance will be found in the muslin bag. This is *gluten*, the real flesh-

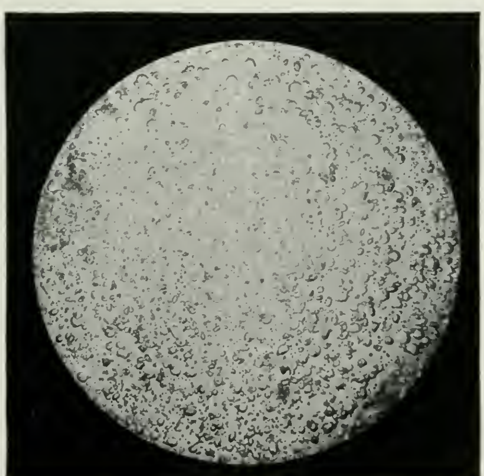


FIG. 3.—WHEAT STARCH.

forming element which gives bread its true value.

The conversion of starch into sugar is a process very extensively carried on by nature, both in the vegetable and animal kingdoms. In every germinating seed this chemical change is going on; every ripening fruit is developing its sugar at

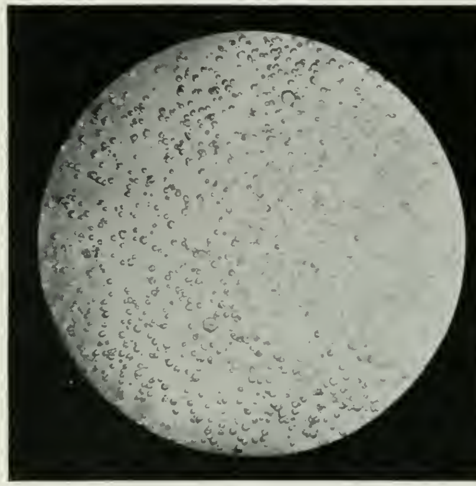


FIG. 4.—SAGO STARCH.

the expense of the starch; and every sweet root, tuber, or esculent owes its excellence to the same transformation.

Starch is insoluble in cold water, but dissolves in hot water, forming a gelatinous solution by the breaking up of the little starch-granules, which, under the microscope, are seen to differ in size and shape according to the source whence they are derived. The microscope is the only means by which one form of starch can be distinguished from another, and thus becomes an important instrument in the hands of the analyst for the detection of food adulteration. The granules of potato (Fig. 1) and arrowroot starch (Fig. 2) are much larger than those of the cereal grains (Figs. 3 and 4), and are elongated, resembling somewhat a mussel-shell in outline.

There are five classes of starch :—

(1) The potato group, oval or ovate grains, with *hilum* and concentric rings well marked.

(2) The leguminous group, consisting of round or oval grains, concentric rings all but invisible, with a well-marked *hilum*.

(3) The wheat group, round or oval cells, the *hilum* and concentric rings being invisible.

(4) The sago group, which have their granules truncate at one end.

(5) The rice group, with polygonal granules. The starch of oats belongs to this class.

The transformation of starch into sugar is a phenomenon equally common in the animal kingdom. It takes place in our

FIG. 5.—SUGAR CRYSTALS.

own bodies whenever the process of digestion is proceeding. The metamorphosis is commenced by the saliva, and such is its energy that sugar has been detected in starch that has been in contact with the saliva for fifteen seconds only. This fact furnishes a cogent reason for the due mastication of our food.

Sugar is so generally distributed in nature, both in plants and their fruits and in the bodies of animals, that considerable importance must be attached to it as an article of diet. It is found in the liver and muscles, in milk and other secretions, in the sap of trees, in flowers as nectar, in cereals, and in every species of edible fruit—in short, there is hardly a dish served up to table, whether derived from the animal or vegetable kingdom, that does not contain more or less of it naturally, though it may be in a disguised and unrecognisable form. There are several varieties of sugar, differing from one another in solubility, sweetness, and crystallisation, such as cane-sugar, grape-sugar, fruit-sugar, and milk-sugar.

The one which we are most familiar with is *cane-sugar*, which in formula is written $C_{12}H_{22}O_{11}$—that is to say, it is built up of 12 atoms of carbon, 22 of hydrogen, and 11 of oxygen. Cane-sugar is obtained principally from the stems of the sugar-cane (*Saccharum officinarum*) (Fig. 7), but is frequently prepared from the stalks of maize or Indian corn. One gallon of the juice of the former yields about one pound of sugar. The charring and consequent discoloration, which so often occurred under the old system, are avoided by modern methods of preparation, and whiter and finer crystals are produced.

When allowed to evaporate spontaneously, sugar produces large prismatic crystals, familiar to our young people as sugar-candy. The amount of sugar contained in different vegetables varies from 2 per cent. in peas, 3 per cent. in turnips, 6 per cent. in carrots, to 45 per cent. in the beetroot (Fig. 6).

As an article of diet sugar holds a very important place. Its universal distribution may be taken as strong evidence of its utility; and the experiments of physiologists, as well as the instincts of mankind generally, point to the fact that its action on the human system is as salutary as its taste is delightful. There seems to be a natural craving, especially amongst children, for this substance, and this alone is an indication which is sufficiently significant.

Dr. Edward Smith, from a series of elaborate experiments, found that sugar facilitated the function of respiration by increasing the exhalation of carbonic acid: if this be true, persons somewhat advanced in years may advantageously "go shares" in the brandy-balls and "bulls'-eyes" which afford so much

solace to their grandchildren under the heaviest trials.

Like all other innocuous substances, sugar may be abused—or, rather, we may abuse ourselves by the intemperate use of it.

The fiction that pure sugar rots the teeth need not deter us from its use; there are no grounds, chemical or physiological, for entertaining such a notion. Any kind of matter of an adhesive nature,

Supplied by Messrs. Licht & Co., Magdeburg.

FIG. 6.—A FIELD OF SUGAR BEET AT MAGDEBURG.

if not washed off, will promote decay of the teeth; and therefore sugar in this respect is no worse than pastry, puddings, or oleaginous foods.

The other sugars need not occupy our attention long.

Grape-sugar, or *glucose*, is one of the simple sugars, having the formula, $C_6H_{12}O_6$, and is that found in grapes, dates, figs, and the fruits and juices of many plants, and also in the blood of animals and the white of eggs. It is a cheap form of sugar, commonly used by confectioners and others. It may be prepared from starch by the action of dilute acids, which are afterwards neutralised by lime; it is prepared in this manner commercially on a large scale.

Lactose is a sugar peculiar to milk. It is found present to the extent of about 5 per cent., and is largely prepared in Switzerland, having considerable importance as an article of commerce.

Now let us turn to the oleaginous substances. Fat and oil are compounds of considerable physiological interest and importance. "All skin and bone" is a condition of things notoriously uncomfortable, but such a physical condition would speedily be brought about by eliminating from our diet every form of oleaginous matter. There are few parts of the body in which fat ought not to be found, if nutrition has been properly effected. Besides layers of fat between the muscles—or flesh—and the different internal organs, and the superficial layers, which by their excess give rise to corpulence, there should be fat in the substance

of the muscles themselves; it is present in the brain, it lubricates the joints, exudes through the pores of the skin in the form of perspiration from the oil-glands beneath, and finally, it can be expressed

Photo: Cassell & Co., Ltd.

FIG. 7.—THE SUGAR CANE. (*SACCHARUM OFFICINARUM*).

from the liver, heart, and other organs of the body.

It is no less common in the vegetable world. In the solid or liquid form it is found in nearly all seeds and fruits. The value of these fatty substances as heat-givers is practically and instinctively tested by the inhabitants of all cold countries.

A Greenlander would regard a meal of whale-blubber as a dainty feast, and a quarter of a seal as only a sufficiency; while a Russian of the northern provinces can manage to dispose of ten and twelve pounds of fish or meat daily without any uncomfortable strain on his digestive organs. This is intelligible only on the chemical theory already explained. In Arctic countries we must remember that the temperature is often as low as 40° below the zero of Fahrenheit, while that of the human body must be maintained at $98\frac{1}{2}°$. This gives us a difference of $138\frac{1}{2}°$, and the necessity for increasing the activity of the respiratory function at once becomes apparent. This is effected by an increased consumption of carbon, which, by its union with oxygen within the body, causes the generation of heat. Now, in 100 lb. of fat there are 77 lb. of carbon, so that the Greenlander's *penchant* for blubber is not the result of gluttony, but instinct.

Fats are composed principally of *stearin* and *olein*, the former being most abundant in solid fats, and the latter in oils. If mutton suet is pressed between several folds of blotting-paper the olein is absorbed, and the stearin remains as a white mass, harder and more translucent than the original suet. A pound of mutton suet contains about three-quarters of a pound of stearin, while the same weight of olive oil contains but one quarter of a pound.

Butter may be looked upon as a fat, though in reality it does not consist of one fat only, but is built up of a considerable number of fats. Its physiological effects are the same as those of oily substances generally. As bread is deficient in fat, the use of butter as an accompaniment to our slice of bread is thoroughly rational. To be beneficial, it must be pure. There is probably more bad butter in the market than bad bread. The cheap sorts are often adulterated with margarine, which is a mixture of refuse fats and vegetable oils; while the suspicious whiteness of the

mixture may be covered by annatto, a colouring matter derived from the pulpy seeds of *Bixa orellana*, of Central and South America. Annatto is also used occasionally to heighten the colour of Cheshire cheese.

A more innocent source of adulteration is water, which is added to increase the weight. About 12 per cent. of water is the natural proportion present in butter, but as much as 18 per cent. is often to be found, part of which can easily be removed by pressure. Our constitutions do not suffer much by this method of adulteration ; but it is certainly not pleasant to be made to pay fourteenpence a pound for what we can get out of the tap for nothing.

A few words are now due to *albumen*. This is the most important of the flesh-forming elements, and is that part of our food upon which nutrition mainly depends; for, take away the *albumen* and the *gluten*, which is a substance of a similar nature, and starvation must speedily follow, no matter how liberally we may partake of starch, sugar, and fat. "Albumen" is found in almost every fluid of the body except the bile. It is an essential part of the blood, and an important constituent of the brain, the spinal cord, and all the nerves emanating from it. It is present in the humours and crystalline lens of the eye ; in the glands or secreting organs, as the liver and kidneys ; in the *synovia*, which lubricates the joints and hinges of the machine, etc. In the white of egg we have albumen in a tolerably pure state, and we are all familiar with the property which that viscid fluid has of coagulation, or of becoming solid by the application of heat, when it loses its transparency and becomes opaque and white. The value of albumen from a dietetic point of view will be fully appreciated when we call to mind the extraordinary metamorphosis it undergoes in the hatching of an egg. The bones in their gelatinous state, the muscles, the blood, the feathers, beak, and claws are all produced at the expense of the albumen by the action of some hidden and marvellous vital force upon its chemical elements. An egg, then, is a highly desirable accompaniment to our breakfast. If you can eat two eggs, by all means have them ; you will thereby secure more available nutriment than can be derived from seven or eight ounces of cooked meat. Take care that they are fresh, or not more than twelve days old in cold weather, and that they are boiled for three and a half or four minutes only. Albumen is composed of the four elements, carbon, oxygen, hydrogen, and nitrogen, in addition to 2 per cent. of sulphur. When we use a silver spoon to eat our egg with, the metal is blackened. This is owing to the formation of silver sulphide, or the chemical union of the sulphur of the egg with the silver of the spoon. The bowl of an egg-spoon should be silver-gilt.

Fibrin is the nutritive element in meat and fish, and resembles albumen in composition. As we have not so much as a rasher of bacon for our breakfast, we shall not dwell upon this substance, Fibrin, but go on to speak of that modification of it called *gluten*, to which seeds and grains owe their nutritive value. It is the substance left in the muslin bag as the result of the experiment for the separation of starch already described. It is viscid and tenacious, resembling glue, and cannot be long kept without undergoing decomposition. The claim of bread to be considered the "staff of life" depends upon the presence of gluten ; and the comparative nutritive power of the cereals may be best estimated by ascertaining the relative proportions taken up by this substance. It varies in different bread-stuffs from $2\frac{3}{4}$ oz. per pound in oats to a quarter of an ounce in a pound of potatoes. *Casein* is the flesh-forming albuminoid in cheese.

The method of making bread is too well known to require description, but it is not so generally known that the action of the ferment known as yeast is to transform a portion of the starch into sugar, and ultimately into carbonic acid gas and water, with a trace of alcohol. The baker, however, does not care about the alcohol, or the water, or the sugar ; his sole object is to secure the services of the carbonic acid gas (CO_2), which, in endeavouring to escape from the heated mass, distends it, and imparts to it that spongy character without which bread would be unfit for daily use. Without the employment of this gas to give the necessary porosity, the loaves would be turned out in the condition of pudding. Something approaching this condition is seen in bread that is "slack-baked," which is heavy, either from too much water having been used in the mixing, or from the employment of insufficient yeast to develop the required volume of gas. Any method by which carbonic acid may be generated within the dough can be adopted in bread-making. Thus, if we mix with the flour bicarbonate of soda, and knead it with water containing tartaric acid, decomposition of the salt will take place. Carbonic acid will be evolved, and tartrate of soda left in the bread. This method is often adopted in making buns and light cakes. A third method is that followed in making the now well-known aërated bread, and which was first suggested by Dr. Dauglish. By this method the flour is mixed with aërated water. Under pressure, water can be made to absorb six or seven times its own volume of carbonic acid, the whole of which it gives off again when heated. The flour is well mixed with the charged water in a strong vessel by means of revolving levers, and is then rapidly transferred to the baking-tins by ingenious machinery, so that all handling is rendered unnecessary. When the tins are placed in the oven, the heat at once acts on the contained gas, which escapes, and gives the required lightness and porosity to the loaves. This method has many advantages. There is no loss of starch, there are no products of decomposition left in the bread, and the fingers (not to say feet) of the workmen are kept clear of the "sponge." It has also the merit of expedition, the whole process occupying but half an hour. It is not likely, however, to supersede fermented bread altogether, as its taste is less sweet, and it rapidly becomes dry and hard.

Those with whom brown bread agrees should use it in preference, as the bran with which the flour is mixed is rich in gluten, chiefly found on the outside of the grain, or in that portion which the miller removes by his grindstone ; in very white bread, on the other hand, the flour by repeated sifting has been deprived of much nutritive matter, and the proportion of starch consequently becomes excessive. The popular prepossession in favour of very white bread offers an incentive to bakers to adulterate their flour with alum, the alumina of which combines with the phosphoric acid of the partially decomposed gluten, and forms aluminium phosphate. This phosphate is insoluble, hence the great loss of the invaluable phosphoric acid to those consuming bread adulterated with alum. Alum is an astringent, and therefore cannot be taken in an article that we are using every day, such as bread, without giving rise ultimately to injurious consequences. The bitter taste that it imparts to bread, when employed in large quantities, is sufficiently indicative of its presence and is easily noticed. It may also be detected by the logwood test. Infusion of logwood assumes a purple hue in presence of alum.

It is commonly believed that new bread is most indigestible; hence the advice never to eat new bread.

The relative digestibility of new and stale bread is a subject which has not yet

been properly settled. The majority of people complain of new bread causing indigestion, especially when they only partake of it occasionally, and it would seem that when they do, they eat more of it than is good for them—far more than if stale bread were put before them; hence the trouble.

With *coffee* we have already made gastronomic acquaintance. The Liberian coffee-shrub is shown in Fig. 9. The fruit resembles a cherry, and is at first red, but ultimately turns black. It contains two seeds, having their flat sides in contact, and surrounded by a tough integument or skin. The pulp is removed by maceration in water, and the seeds with their covering attached are then dried. The integument is removed by the action of rollers, so arranged as not to crush the seeds. Much of the flavour of coffee depends upon the roasting, which is therefore a process of considerable importance. If over-roasted the aroma is destroyed, so that beans having a black or charred appearance ought to be rejected. The roasting is conducted in a cylinder, made to revolve slowly, so that the contents are uniformly heated. The proverbial excellence of French coffee is probably due to the care and judgment brought to bear upon the roasting, which is done very frequently, sufficient only being roasted to last a short time, rather than to any peculiar method of preparing the beverage. The active principle which gives coffee its most characteristic property is a poisonous alkaloid called *caffeine*. It can be obtained in beautiful silky crystals, and, strange to say, is identical with the *theine* of tea, in which, however, there is 1 per cent. more of the alkaloid than in coffee. On this account tea exerts a more prejudicial influence on the nervous system than coffee. On the other hand, coffee dries the skin, while tea moistens it by promoting evaporation. Coffee quickens the heart's action and checks sleep; so that unless the reader happens to be a student cramming for the "little go" by the midnight lamp, or a newspaper editor whose "copy" is yet in his brain, or a policeman on night duty, he should not indulge in a strong decoction of coffee for supper. The practice of taking tea and coffee at high temperature is itself injurious, independently of the effects arising from the caffeine. It weakens the tone of the stomach by impairing its elasticity and contractility. Coffee should be used freshly ground, because the powder not only loses its aroma by keeping, but, like

Photo: Cassell & Co., Ltd.

FIG. 8.—THE TEA TREE (*CAMELLIA THEA*).

bone-black. absorbs many times its own bulk of gaseous matters or vapours which may happen to be floating within reach.

Photo: Cassell & Co., Ltd.

FIG. 9.—THE COFFEE TREE *(COFFEA LIBERICA)*.

Coffee is most commonly mixed with *chicory*, which may be regarded as an adulteration, as the law does not permit of this mixture being sold under the name of coffee. Wherever the mixture is sold, it must be labelled a mixture of coffee and chicory. *Cichorium Intybus* (Fig. 10), the source of chicory, is a familiar wayside flower. The root is ground and roasted, and is then almost indistinguishable from ground coffee, to which, however, in chemical properties it is totally dissimilar. The aroma of coffee is altogether wanting; it contains no caffeine or tannic acid, and is mainly starch, gluten, and woody fibre or cellulose. Mixed with coffee, it darkens the colour of the beverage; and its use is further justified by many persons on the ground that it gives "body" to the infusion. What is meant by this "body" is not particularly clear, unless it means a coarse and acrid flavour which disguises the natural bouquet of the coffee. Physiologically chicory is more harmless than coffee, and its use is attended with less cerebral and nervous disturbance; but that is no reason why we should submit to have an article of such inferior value palmed off upon us as genuine Mocha.

Of late years adulteration with such things as roasted dates, figs, and raisins—to say nothing of malt—has become comparatively common. It can at least be claimed for these substitutes that they are harmless. Nothing analogous to caffeine is found in them, but they impart a greater depth of colouring to the infusion, and in the popular mind depth of

FIG. 10.—THE CHICORY *(CICHORIUM INTYBUS)*.

colouring is regarded as being a sign of strength. We get a good instance of this in that pernicious beverage "stewed tea." Tea that is allowed to stand for a long

time to "draw" loses much of its delicious first aroma, but it contains (proportionately) large quantities of the injurious tannin.

Several "brands" of coffee are known in commerce. First we have genuine "Mocha," which has small grey beans; then we have "Java," with its large yellow beans; "Jamaica," with beans of a yellow-green hue; and "Bourbon," with pale yellow beans.

The roast mealie coffee of South Africa can scarcely compare with genuine Mocha in point of flavour, but with a fair quantity of milk and some of the store of sugar which the healthy body requires to keep it going (Fig. 11), it is a refreshing drink.

But we perceive that our coffee-pot is empty, and the stock of bread and butter exhausted: our simple breakfast is therefore at an end.

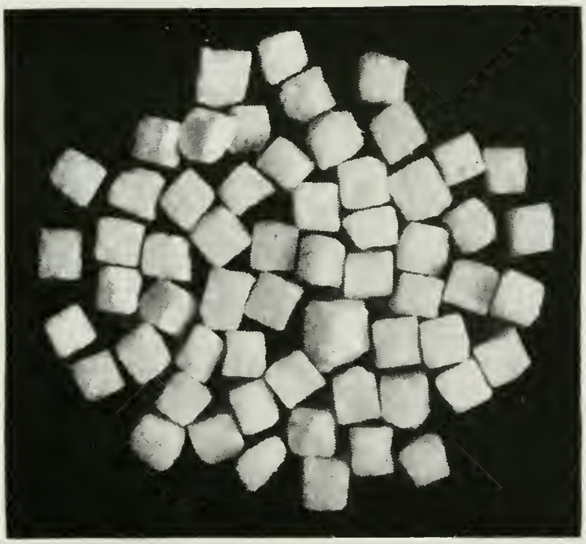


FIG. 11.—FIFTY-NINE LUMPS OF SUGAR.

The body of every full-grown healthy man contains about this amount of sugar.

THE THEORY AND PRACTICE OF VACCINATION.

By F. W. STANSFIELD, M.D.

THE vaccination question, about which so much controversy has raged in this country during the last twenty-five years, is in reality not a plain issue, but is resolvable into three separate questions, viz. :—

1. *Does vaccination prevent, or tend to prevent, small-pox?* In the event of this question being decided in the negative, it becomes unnecessary to go into the other questions. If, however, this question be answered in the affirmative the second question arises :

2. *Is the greater or less protection gained by vaccination worth the risk of other evils which may possibly arise from it?* If this question also be answered affirmatively the further question arises :

3. *Have we, the majority who believe in vaccination, the right to insist on protecting others against their will; or, more exactly, have we the right to insist on protecting young children, unable to decide for themselves, whose parents or other guardians object to their being so protected?*

The first two questions are biological, while the third is political and will not be discussed in the present article.

It is difficult for people in these days, when comparatively few have ever seen a case of small-pox, to realise the state of mind which the word conjured up a century or two ago. Faces pitted by small-pox were so common as to be regarded as normal rather than abnormal, and cases of blindness from it were frequent. In the reports of the London Hospital for the eighteenth century it is said, "As the disease is so frightful, even in its first appearance, and at the same time so contagious and almost inevitable, families of all degrees are thrown into the utmost confusion when it invades any person among them." In advertising for a servant it was customary to stipulate that he (or she) "must have had small-pox in the natural way," and inoculation (*i.e.* the artificial production of small-pox) was resorted to "because it delivered people from those apprehensions with which, till they had had small-pox, they were always haunted." Macaulay, in his History of England, referring to the death of Queen Mary from small-pox in 1694, says, "That disease, over which science has since achieved a succession of glorious victories, was then the most terrible of all the ministers of death. The havoc of the plague had been far more rapid; but plague had visited our shores only once or twice within living memory, but the small-pox was always present, filling the churchyards with corpses, tormenting with constant fears all whom it had not yet stricken, leaving on those whose lives it spared the hideous traces of its powers, turning the babe into a changeling at which the mother shuddered, and making the eyes and cheeks of the betrothed maiden objects of horror to the lover."

Towards the end of the eighteenth century it was a matter of current country gossip that persons who had had cow-pox (a disease of the udders of cows, which was occasionally caught upon the hands of milkers) were not liable to take small-pox; and it is recorded that one Jesty, a Dorsetshire farmer, in 1774 inoculated his wife and his two sons with the cow-

pox in the belief that they would thus obtain protection.

Edward Jenner no doubt heard of this country rumour, and thought it worthy of systematic investigation. In 1796 he inoculated a number of people with cow-pox, taking lymph from the hand of a dairy-maid who had been infected when milking, and these persons were afterwards inoculated with true small-pox but were found to be insusceptible. As a proof that Jenner had the courage of his convictions, it may be mentioned that after he had vaccinated his own son, he caused the child to occupy the same bed with a small-pox patient, as a test of the efficiency of vaccination as a protective agent. It is not surprising that the publication of Jenner's results, and of those of others following him, caused the practice of vaccination to be eagerly taken up and widely adopted, not only in this, but in almost all civilised countries.

Photo: Dr. C. Killick Millard.

FIG. I.—SMALL-POX IN A VACCINATED CHILD.

Compare now the present state of things with what existed a little over one hundred years ago. *Then* there was universal terror of small-pox. *Now* it is so rare that people no longer fear it; they do not know what it is like; very few of the general public have ever seen it, and a considerable number even of medical men are in the came case. This very rarity has caused a certain amount of reaction, and, by leading to neglect of vaccination, has brought about a return of the disease in certain places. In Germany, however, where vaccination and re-vaccination are rigidly enforced, there is practically no small-pox beyond imported cases.

Statistics might be quoted showing the enormous decline in the mortality from small-pox since the introduction of vaccination, but this is really unnecessary, since the fact is admitted on all hands. It is contended, however, by the opponents of vaccination, that this decline is due to improvements in general sanitation, and not to vaccination. It is important, in order to see the full effect of vaccination, that the death rates from small-pox should be given at successive periods of life. Unfortunately, the causes of death were not abstracted in combination with ages, in the official returns, until 1847. We cannot, therefore, compare the small-pox mortality at different age periods before and after the introduction of vaccination. We can, however, compare periods in which it has

been practised to a varying extent. The period since 1847 can be divided into three sub-periods:

1. From 1847 to 1853, inclusive, in which vaccination was purely optional.

2. From 1854 to 1871, in which vaccination was obligatory, but in which there were no effectual means of enforcing it.

3. From 1871 onwards, in which vaccination was more or less rigidly enforced, Boards of Guardians being obliged to appoint vaccination officers in each district.

The following table, taken from Newsholme's "Vital Statistics" (1889 edition), shows the changes which took place in the death-rate from small-pox during these three sub-periods.

MEAN ANNUAL DEATHS FROM SMALL-POX AT SUCCESSIVE LIFE-PERIODS PER MILLION LIVING AT EACH SUCH LIFE-PERIOD.

Sub-Periods.	Age.						
	All ages.	0—5	5—10	10—15	15—25	25—45	45 and upwards.
(1) Vaccination optional, 1847-53	305	1617	337	94	100	66	22
(2) Vaccination obligatory but not efficiently enforced, 1854-71 ...	223	817	243	88	163	131	52
(3) Vaccination obligatory and more efficiently enforced by vaccination officers, 1872-80	156	323	186	98	173	141	58
Entire period of obligatory vaccination, 1854-80	198	633	222	92	167	135	55

From a consideration of these statistics it is clear that with the gradual extension of vaccination there has been a gradual decline in the death-rate from small-pox *at all ages combined*, but that this decline is exclusively among children under ten years of age, and, indeed, chiefly under five years, in which group of ages the mortality fell 80 per cent. After this age the mortality begins to rise, and in the last column—*i.e.* over forty-five years of age—it has actually risen 164 per cent. In other words, with compulsory vaccination the mortality among children under five has dropped to little more than half of what it was with optional vaccination, whereas at ages over forty-five the mortality has increased to more than double what it was before.

What is the explanation of these remarkable figures? The orthodox explanation is that it is due to vaccination. Experience, which has been accumulating since the time of Jenner, shows that, instead of vaccination having the same protective influence as an attack of small-pox (as Jenner imagined), its protection is less perfect and especially is less *permanent*, and steadily diminishes with age, though probably some trace of it remains in most cases throughout life. Vaccination, therefore, being performed in infancy has the maximum of protective influence in the first few years of life. Before the introduction of vaccination but few persons escaped having small-pox at some period of their lives, and the great majority had it when young (just as is still the case with measles). Of these a large proportion died, making the small-pox mortality for the early age-periods high; but those who recovered were effectively protected against another attack, and, as they formed a large proportion of the adult population, the death-rate from small-pox amongst the older members of the community was generally low. The effect of the introduction and extension of vaccination, therefore, was to reduce the mortality among the children; but because the adult population were no longer protected by having had small-pox, and the effect of their early vaccination having more or less worn out, their small-pox mortality was increased.

The common-sense lesson to be drawn from these facts is that the protection of vaccination should be renewed from time to time by re-vaccination, and abundant experience shows that if this be done before the effect of former vaccination has been too much weakened by lapse of time, it is not only free from danger, but causes practically no discomfort or inconvenience. My own experience, gathered from some thousands of re-vaccinations, is that, other things being equal, the reaction produced is directly proportional to the time that has elapsed since the last vaccination. I have also noticed that the effect of vaccination " wears out " much more quickly during the growing period—*i.e.*, up to the twentieth year or thereabouts—than it does during adult life. For instance, if a child, vaccinated in infancy, be re-vaccinated at ten years old, there will be no difficulty about " taking," and there will be a distinct, though mild, re-action, and the arm will be practically well in a week or ten days. If, however, the first re-vaccination be delayed until the age of twenty, there will be a rather severe reaction—much more than in primary vaccination in infancy—and the patient will be more or less disabled for a week or so. If this patient be again re-vaccinated at thirty years of age, the reaction will be as mild, or milder, than in the case of the child re-vaccinated at ten, and will cause no inconvenience or discomfort worth notice. As age advances the interval required for the vaccination to wear out gradually lengthens, so that a person of sixty who has been re-vaccinated once or twice in adult life will often be found quite insusceptible to vaccination, and is, no doubt, equally impervious to small-pox. On the other hand, the most severe reactions are met with in stout, middle-aged or elderly people who have either never been vaccinated at all or only in infancy. In these cases vaccination often causes severe indisposition and great discomfort—sometimes severe pain—and not rarely necessitates rest in bed for several days. *Primary* vaccination in adults at any age is often a somewhat formidable affair, especially if, as often happens, the patient goes on using the arm until compelled to desist by increasing pain and swelling. Even in these extreme cases, however, the trouble is a mere bagatelle as compared with the evils and dangers of small-pox.

With regard to the contention that the modern decrease in small-pox mortality is due to general sanitation rather than to vaccination, it is quite unsupported by evidence showing any direct connection between bad drainage and small-pox. In this respect the disease is like measles and whooping cough, both of which remain as prevalent as formerly, in spite of sanitary improvements. Experience shows that clean people, who live in healthy surroundings, are just as liable as others to take small-pox if exposed to contagion and unprotected by vaccination. But even if we waive this and grant that improved sanitation may have had some influence in decreasing the small-pox mortality, it cannot account for the whole. Dr. Newsholme calculates that one-seventh of the diminution is the utmost that can, by any stretch of liberality, be allowed to general sanitation in this matter. When we come to apply the theory of general sanitation to explain the altered age incidence of small-pox, it is seen that it will not fit at all—it cannot possibly be made to fit. We have seen that before vaccination small-pox was chiefly a disease of children; now it is chiefly a disease of adults.

In order to explain this change on the theory of general sanitation we have to suppose that cleanliness is good for people only up to the age of ten years, and that after that age it is not only useless, but actually injurious in making them more

liable to small-pox—that what is sauce for the gosling is not sauce for the goose and gander, which, as Euclid would say, is absurd.

In most modern sets of statistics a great stumbling-block to the inexperienced inquirer is the fact that there are generally more vaccinated than unvaccinated patients, and that when the cases are divided into "vaccinated" and "unvaccinated," without further discrimination, the death-rate among the vaccinated is sometimes as high as among the unvaccinated. If the statistics are examined carefully it will be found that in these cases the vaccinated class consists largely of persons whose vaccination protection has worn out from lapse of time, and includes also many persons whose vaccination was very imperfect; and that the unvaccinated class includes persons who, although never vaccinated, are protected by a previous attack of small-pox.

The table of Dr. Gayton's cases, also published in Newsholme's "Vital Statistics" (1889 edition) is well worthy of careful study. It is a digest of 10,403 cases treated by Dr. Gayton in the metropolitan small-pox hospitals. The cases are classified into age-periods, and are also divided into four series, which may be called well vaccinated, badly vaccinated, doubtfully vaccinated, and unvaccinated. When all ages are taken together it is found that the death-rate among the well-vaccinated is 3 per cent., among the imperfectly vaccinated it is 9 per cent., among the doubtfully vaccinated it is 27 per cent., while among the confessedly unvaccinated it is 43 per cent. When children under five are considered alone it is found that among the well vaccinated the number of cases is very small, and the death-rate absolutely *nil;* among the imperfectly vaccinated the number of cases is larger, and the death rate is 9 per cent. under two, and 12 per cent. from two to five years of age; among the doubtfully vaccinated the numbers are also larger than in the first class, and the death-rate is 40 per cent.; while among the unvaccinated the number of cases is nearly double that of all the other classes put together, and the death rate is 66 per cent. under two, and 50 per cent. from two to five years of age.

The most awful consequences, such as small-pox, tubercle, leprosy, syphilis, erysipelas, and cancer, have been alleged to result directly from vaccination.

If the reports of cases be inquired into, it is found, in the vast majority of them, that the story will not bear investigation. *I have never yet found a genuine case of transmission of any of these diseases by vaccination, even under the old system of arm to arm vaccination;* while under the present system of inoculation by glycerinated calf-lymph with full antiseptic precautions *it is practically impossible for such a thing to occur.* It does occasionally—very occasionally—happen that eczema, although probably not *transmitted* by vaccination, is roused into activity by the irritation of vaccination when already dormant in the system. I have met with some half dozen or so cases of this kind among many thousands of vaccinations. In every case, however, the eczema promptly subsided upon proper treatment, and left the patient as well as before. When one considers how very prevalent eczema is among the children of the poor, even before they are vaccinated—probably 90 per cent. of postponements of vaccination are on account of eczema—it is a marvel that there are not more cases of eczema breaking out *coincidently with* vaccination. Almost every vaccinator (the writer among them) has had cases where a vaccination has been postponed for some other reason—perhaps for the convenience of the mother—and during the

interval eczema has broken out and would certainly have been put down to vaccination had the operation been performed at the time first appointed. Of course, other diseases besides eczema may occasionally break out coincidently with, or shortly after, vaccination, and these are all duly put down to the discredit of vaccination. Stories are spread from mouth to mouth and exaggerated at each step, so that the most insignificant incident is rapidly magnified into a calamity. The story of the young woman who lost her arm through vaccination crops up in almost every town where much vaccination is going on, and is repeated with much and constantly varying circumstantiality of detail, but is always found to be a pure invention when investigated. It might be imagined—and no doubt it often is imagined—that where there is so much smoke there must be some fire, some foundation of fact for all the stories circulated. The foundation is to be found in the constitutional laziness of human nature—the desire to avoid trouble. The great majority of people never having seen small-pox, are inclined to look upon it as a mere bogey—a thing perhaps invented to frighten them—and they will not, if they can help it, submit to any inconvenience to avoid a danger not immediately present. Consequently, they often lend a willing ear to stories of vaccination horrors, and become either active resisters or conscientious objectors. The case is different, however, when small-pox is next door, or a relative has died of it: conscientious objections disappear like snow before the summer sun, and erstwhile objectors besiege the public vaccinator in clamouring crowds.

We come now to the very interesting question of the pathology of *vaccinia*—*i.e.* how and why does vaccination protect from small-pox? In the first place, we do not actually know how or why an attack of small-pox protects against future attacks. That it does so, however, just as measles protects against measles, and scarlet fever against scarlet fever, scarcely anyone seriously doubts, in spite of a number of exceptions to the rule in each case. There are alternative theories, upon which it is supposed that an attack of infectious disease either uses up some substance in the body which is necessary to the growth of the disease, or else produces some substance which is antagonistic to that growth. The first of these theories is supported by analogy with what is known of the rotation of crops in farming, while the second is more in accordance with the poisoning of ground by animals for their own species when overcrowded in any particular area. With regard to vaccination, the theory of Jenner was that cow-pox was simply small-pox in the cow, deprived of its virulence and infectious quality by the tissues of that animal. It is certain that the cow is incapable of taking natural small-pox as such—*i.e.*, in its unmodified form. Many attempts have been made both to prove and to disprove Jenner's theory, but in most cases the attempt to transfer human small-pox to the cow has had simply a negative result. As far back as 1840, however, Ceely and Badcock succeeded in inoculating small-pox in the cow and in producing effects which closely corresponded to cow-pox. More recently it has been found that if the natural small-pox be first inoculated into human beings or into monkeys it can then be readily transferred to the cow. Further, the matter from such experiments, transferred to man, has been found to produce effects undistinguishable from the ordinary vaccine vesicle. It may be taken, then, as practically settled that vaccinia is simply modified small-pox, and that it protects from small-pox for the same reason (whatever that may be) that small-pox itself does so.

In 1894 Dr. Klein, bacteriologist to the Local Government Board, succeeded in finding, in vaccine lymph and in small-pox matter, organisms which were apparently one and the same. More recently Kent, in England, and Councilman, in America, have made similar, but more definite observations. Councilman's observations, which were only announced at Boston in the April of 1903, bid fair, if confirmed, to lay bare the life history of the true cause of small-pox. This is stated to be an organism belonging to the *protozoa* or lowest known forms of animal life, and is therefore not one of the bacilli, which belong to the vegetable kingdom. The protozoon of small-pox has two life-cycles, corresponding to what is known of the protozoa in general. Both cycles of existence go on within the living cells of the body, the first being simply a process of continuous division, and taking place outside the nucleus of the cell; the second takes place within the nucleus and appears to go on to a process of spore or egg formation. It is conjectured to be of a sexual character, and the final spore-like bodies are regarded as the infecting agent of the disease. It also appears to be demonstrated that *vaccinia* represents the first, or extra-nuclear, phase of the organism, but that the production of true small-pox is dependent upon the invasion of the nuclei—the second or intra-nuclear phase. If the organism be inoculated into the calf or rabbit vaccinia is produced; but if into the monkey small-pox is the result. The work which led to this announcement has been carried on for the past two years at the small-pox hospitals of Boston, United States, and at the pathological laboratory of the Harvard Medical School. If Councilman's results should be borne out by further examination—and they have already been, to some extent, confirmed by independent authority—they place upon an exact scientific basis what was already known upon an empirical basis. Should they, however, be not confirmed, small-pox will still be controllable by vaccination as before, whatever may be the true explanation of the process.

The use of detailed statistics has been largely avoided in this paper. Should the reader care to investigate statistics for himself, he will find them in abundance in the final report of the late Royal Commission on Vaccination,* in the various publications of the Jenner Society, and in Dr. McVail's "Vaccination Vindicated." The statistics of the epidemic in 1896 at Gloucester, where infant vaccination had been almost entirely neglected for many years, are extremely instructive, as showing that, in the absence of vaccination, the greatest mortality tends to be among children, just as was the case before the introduction of vaccination. This epidemic was, indeed, a modern reproduction on a small scale, of the horrors of pre-vaccination times.†

The following are the conclusions at which I have arrived from a considerable experience and a careful study of all the evidence reasonably available:—

1. Vaccination has a powerful tendency to protect against the taking of small-pox by those exposed to its contagion. This protection is, however, less permanent than that given by a previous attack of small-pox.

2. Vaccinated persons, if they do take small-pox, are much less liable to have it in a severe form, and are very much less liable to die from it.

3. The risks of vaccination were insignificant even under the old arm-to-arm system, and have been reduced to almost a vanishing point by the new system of vaccination with glycerinated calf lymph, and with antiseptic precautions. It is

* Price 1s. 10d.

† *See* "A Plea for the Children, Jenner Society, Gloucester.

still possible, however, by carelessness and neglect of cleanliness, for bad results to ensue.

4. In order to be *absolutely* safe from small-pox it is necessary for vaccination to be renewed *as often as it can be performed successfully.* This period varies in different individuals, and may be taken approximately as about once in five years during the growing period, and once in ten years afterwards. For practical safety, however, it may be taken as once in ten years during the growing period, and once in twenty years afterwards—say five or six times in a long lifetime. If this system be adopted, there will be practically no pain and no appreciable inconvenience arising from it.

Photo: Cassell & Co., Ltd.

FIG. 2.—GLOUCESTER CEMETERY, WHERE THE NUMEROUS VICTIMS OF THE SMALL-POX EPIDEMIC OF 1896 ARE BURIED.

FIRE-DAMP AND THE SAFETY LAMP.

THE side of a pool of stagnant water is not the most attractive spot that could be selected for the purpose of studying nature; but we should not have to remain there long before noticing that the surface of the water is from time to time disturbed by the rising of bubbles. If we stir up the material at the bottom of the pool with a stick, the bubbles will rise much more rapidly. They may rest for a moment on the surface of the water, but they will then burst, and there will be nothing visible left. Anyone with an inquiring turn of mind will at once ask, "What causes these bubbles? They look like air bubbles; but how can air be given off from the bottom of a pool?" In order to determine what the substance is which thus rises through the water and escapes, we must in some way get possession of it, and then study its properties. To accomplish this it is only necessary to bring a good-sized bottle under the surface of the water in the pool, and, after it is filled, invert it, and place a funnel in its mouth. The funnel should be tied to the bottle to prevent its falling. Now, if this piece of apparatus is placed over the rising bubbles, they enter the bottle instead of escaping into the air, and as they enter an equal volume of water is driven out, and gradually the bottle becomes filled with the gas. If the bottom of the pool is stirred up, the amount of gas which rises is increased in quantity, and the process of filling the bottle is hastened. The accompanying illustration (Fig. 1) will show clearly how the apparatus is managed.

FIG. 1.—COLLECTING MARSH GAS FROM A STAGNANT POOL.

A very slight examination is sufficient to show that the gas in the bottle is not ordinary air. If a lighted match be applied to it, it takes fire and continues to burn. If examined in the laboratory by the most refined methods of chemical analysis, it is found to consist mainly of one gas, while mixed with it are some other substances which may be regarded as impurities. The fact that it is found in stagnant pools or, in general, in marshes, has given it one of its names, *marsh gas*. It is commonly spoken of as *light carburetted hydrogen* —the CH_4 of the chemist—to distinguish it from *heavy carburetted*, or *bi-carburetted, hydrogen*, or olefiant gas, as it is sometimes called, which has the chemical formula of C_2H_4. The expression CH_4 means that one "atom" of carbon combines with four "atoms" of hydrogen to form one molecule of *light carburetted hydrogen.*

Photo: Cassell & Co., Ltd.

FIG. 2.—WORKING ON THE FACE OF THE COAL IN THE GRIFF COLLIERY.

Note the safety lamp beside the miner.

Marsh gas is thus known as a *hydrocarbon*. A very large number of these hydrocarbons are known to chemists, and a great deal of time and labour has been spent in studying them. It is now known that most of those intricate and interesting substances which are found in the organs of plants and animals may be derived from the hydrocarbons. Petroleum is made up of a number of different hydrocarbons. Some of these are gases at ordinary temperatures, some are light liquids which are converted into vapour by a very slight amount of heat, while others require a greater amount of heat, and so on. Now, of all the hydrocarbons, marsh gas is the simplest. It is, as it were, the mother substance of the whole group, and, in consequence, it is of great importance in chemistry, and a complete account of it would involve a discussion of many of the most profound problems of science. But let us rather keep in mind matters of more general interest to those who are not chemists, for there is enough to occupy us profitably without going into abstruse scientific questions. Let us attempt to discover why marsh gas rises from pools of stagnant water ; whether it is found under other conditions in nature ; how we can make it in our laboratories ; and why it has attracted general attention, and, under another name, has become the terror of the inhabitants of coal-mining regions.

In marshy pools there are always the remains of plants in the form of grass and leaves, and these, as we can easily convince ourselves, are undergoing decay. They are made up to a considerable extent of carbon, hydrogen, and oxygen, and it appears probable that the marsh gas owes its formation to this process of decay, but without proof we should not be warranted in accepting this conclusion. There may be other substances in the water or under the earth which give rise to its formation. To test this, we may collect some leaves and other parts of plants, place them under pure water in clean vessels, into which no foreign matter can gain access, and then expose the mass to the action of the air and sun. Slowly the process of decay will begin, and in time we shall have an artificial stagnant pool. It will be found that this will conduct itself essentially like the pool in the marsh. The bubbles will rise, and stirring will increase the rapidity with which the gas is given off. On collecting the gas and comparing it with that obtained from the marsh, the two will be found to be identical. The leaves and other materials placed in our tank will be found to have undergone change. They will be seen to be disintegrated and darkened in colour. This experiment proves that marsh gas may owe its existence to the decay of vegetable matter under water, and it is fair to conclude that this is the cause of its formation in marshes.

If the vegetable matter were left exposed to the air, it would also undergo decay, but the products would not be the same. The oxygen of the air would convert all the carbon into carbonic acid, and the hydrogen into water. Under the water, however, there is not enough oxygen to effect these changes. There is, to be sure, some oxygen in the substances themselves, and this combines partly with the carbon, forming carbonic acid ; but there is not nearly enough of it to convert all the carbon in this way, and that which is left combines with the hydrogen to form the hydrocarbon marsh gas. The difference between the process of decay in the air and under water is similar to the difference between burning a piece of wood with free access of air and heating it in a closed vessel. In the former case we know the wood burns up, as we say—that is, it disappears almost completely ; and if we were to examine the smoke, we should find it to consist largely of carbonic acid and water. In the latter case, after high heat has been applied to the vessel, and the change is completed, there is left a black mass, which we call charcoal, consisting mainly of carbon. Among the

substances given off there is always under such circumstances a considerable quantity of marsh gas. The decomposition of the vegetable matter in the closed vessel is to be compared with the decay under water, in so far as both processes are effected without access of air.

The simple experiment with the vegetable matter in the tank of water represents in miniature not only the changes which are going on in marshes, but mightier changes which have taken place in ages past, and which have resulted in the formation of our great coal beds. It has been shown by geological and botanical and chemical examinations that these coal beds are the remains of vast forests which were at one time submerged, and then, under peculiar conditions, underwent partial decay. Among the products formed in the first stages of the process, there would naturally be marsh gas, and it is probable that this gas would continue to be formed as long as the material was undergoing change. At first this would escape for the most part, but as the mass of coal by continued change became harder and harder, and as it came to be covered by layers of earth, and these in turn became harder and harder, forming a more or less impervious layer above the coal, the escape of the gas would be, at least, partly prevented. It would tend to collect in cavities in the coal, and there remain, accumulating slowly, until by its own ever-increasing pressure it forced an opening of escape, or until man, in his advances upon nature's stores, set it free by accident.

Of course, unless marsh gas is actually met with in nature in connection with coal beds the above remarks would be but idle speculation, and would scarcely be worthy of attention. But if, reasoning upon a basis of well-established facts, we are led to expect the formation of a certain substance under certain conditions, and we actually find that the substance is formed under these conditions, then we may fairly conclude, until evidence to the contrary is produced, that our reasoning is correct. This is exactly the state of the case with reference to the occurrence of marsh gas. The gas is found in enormous quantities in connection with coal beds, just as we should expect, and not a year passes that we do not hear of its escape, and the awful consequences which usually follow. But we are anticipating.

In some parts of the earth there are fissures in the ground from which a gas is constantly escaping. On the western shores of the Caspian Sea, upon the Apsheron peninsula, at Baku, such a gas is burning, and has probably been burning for ages, forming the celebrated sacred fire of Baku. This place, which is known as *Ateshga*, or the Place of Fire, was formerly visited annually by thousands of pilgrims, and a number of Persian "Guebres"—fire worshippers—still make the pilgrimage thither. This "place of fire" is about a mile across, and upon it stood at one time a temple erected by the fire worshippers. Not even this, however, has been proof against the march of progress, for upon the site of this now vanished temple large petroleum works stand—the emissions of natural gas, which formerly kept the sacred fire going, now serving as fuel for the retorts. The mysterious has given place to the prosaic! The whole country around Baku has at times the appearance of being enveloped in flames. It often appears as if fire rolled down the mountains in large masses with great velocity; and at night a bright blue light is observed to cover the western range of hills. The gas has been collected at Baku and examined, and found to be mainly marsh gas, and it is supposed that the fissures from which it escapes communicate with subterranean coal beds, in which it accumulates under pressure, and then forces its way out through the earth. In the village of Fredonia, in the State of New York, the same gas also escapes, but it has never had the honour of supplying sacred fire for the New World;

it has been treated prosaically, and utilised for illuminating purposes, nature, in this case, enabling the inhabitants to dispense with the expensive luxury of gas-works. Wherever there are petroleum wells this gas is present, and escapes from the cavities which are punctured for the purpose of procuring the oil; the escape is in some cases so abundant that the material is utilised for heating and illuminating purposes. The soil for some distance round Baku is saturated with petroleum, and a number of springs have been worked to great advantage.

The chief conditions under which marsh gas is found in nature have been mentioned, and it will be seen that these conditions are probably all of the same general nature. They are such that the decay of vegetable matter can take place without access of air, and this decay may be looked upon as

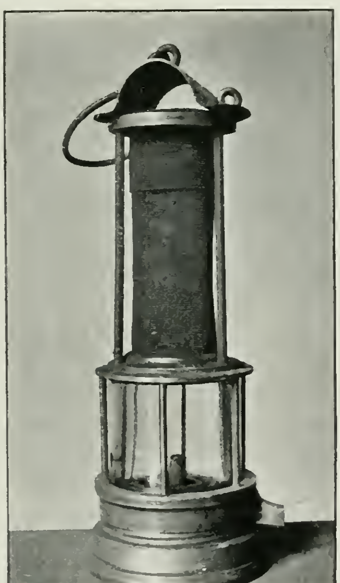


FIG. 3.—SAFETY LAMP; A MODIFIED DAVY.

the cause of the formation of the gas wherever it may be found in nature, whether rising slowly from the bottom of the stagnant pool, bursting suddenly forth from its enclosure in a coal bed, issuing from the fissures which it has made in the earth, or accompanying the other hydrocarbons which go to make up that valuable and complicated substance petroleum.

As was stated above, the gas is formed

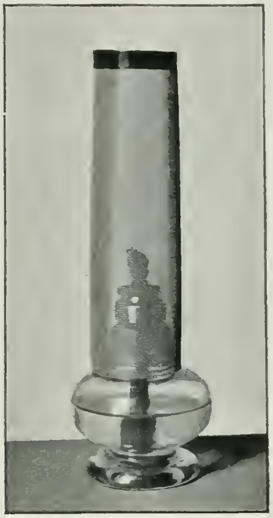


FIG. 4.—ORDINARY LAMP WITH LIGHT ENCLOSED IN GAUZE CYLINDER.

when wood is heated in a vessel in such a way as to prevent free access of air. Many other substances are formed at the same time, some of these being liquid, and others gaseous. All the gaseous portions mixed together form a very good illuminating gas, and in some places it is found to be convenient and profitable to heat wood for the express purpose of manufacturing gas. So, also, when the different varieties of coal are heated in closed retorts, they, as is well known, give off gases and liquids, and leave behind a solid. Some kinds of coal yield much more gas than others, and are in request for the purpose of manufacturing coal gas. Coal gas always contains a considerable quantity of marsh gas Thus it is seen that we may either start from the vegetable matter, and by a series of very slow changes obtain marsh gas; or we may heat it, and obtain the gas at once; or we may take one of the products of decayed vegetable matter—namely, coal—and by heating it obtain the gas.

But while all the processes mentioned lead to the formation of marsh gas, and in some cases in enormous quantities, to obtain it in pure condition for the purpose of study it is much more convenient to simply mix together acetate of sodium and soda-lime, and then heat the mixture strongly. In this way we can obtain possession of any desired quantity, and in purer condition than that which we get directly from nature.

FIG. 5.—A CANDLE "LAMP" PROTECTED BY GAUZE AT TOP AND BOTTOM.

And, now, what are the properties of marsh gas? The fact that it burns has been repeatedly stated. When it burns it is converted into carbonic acid and water, and nothing else. It is not an active poison, but if it were to be breathed into the lungs for any length of time death would ensue from lack of oxygen, in much the same way as in the case of drowning. It has no odour and no taste; but one of its most striking properties is its power of forming explosive mixtures. If it be mixed with air in certain proportions, varying between six and fourteen parts of air to one part of the gas, it only needs a spark to cause the entire mixture to explode with violence. We can, of course, easily make such a mixture in the laboratory, and, if this be brought into a vessel with a large mouth, it may be exploded without danger by applying a lighted taper to the gas at the open mouth. Or evidence of the force of the explosion may also be obtained by inflating a mass of soap bubbles with the mixture and applying a light. It would require but a few such experiments to inspire us with respect for the gas. Other hydrocarbons besides marsh gas have this same power of forming explosive mixtures with air. This is particularly true of the hydrocarbons in petroleum, and the lamp explosions which we hear of altogether too frequently are due to the presence in the petroleum of certain volatile hydrocarbons, which should be removed in the process of refining. These are converted into gases at a low temperature, and when mixed with air give rise to the explosions.

With the facts already in our possession we are prepared to divine the cause of colliery explosions, and for the consideration of certain matters of importance connected with them. No one need be told of the frequent occurrence of terrific explosions in coal mines, often involving enormous loss of life and the destruction of a vast amount of property. From what has been said the cause of these explosions must be clear. Marsh gas escaping from coal-beds is likely to be met with at any time in a coal mine. It may be given off gradually, and in small quantity, and do no harm if good ventilation is kept up; but let new cavities be opened, or let fissures be formed, so as to permit of the escape of a large quantity of the gas, and what will be the consequence? As soon as a mixture of the proper proportions of air and the gas is formed, it only requires the momentary contact of a flame or spark to cause the dreaded explosion. The miners are familiar with the gas, and from the fact that it burns they call it *fire-damp*. In a similar way, carbonic acid, in which breathing is impossible, and which does not burn, is called by them *choke-damp*. The terrors of both of these are encountered in coal mines, and, in fact, in the case of an explosion both may contribute to the fatal results. When the explosion occurs, the "fire-damp," or marsh gas, is converted into "choke-damp," and an occupant of the mine may escape the direct effects of the explosion only to be stifled to death by the choke-damp before he can make his escape.

As the setting free of fire-damp is neces-

sarily connected with the opening of coal-beds, and as the miners must have light to enable them to do their work, explosions would seem to be unavoidable. Of course, we think at once of protecting the flames of the miners' lamps, but if we cut off completely the communication between the flame and the air the flame will certainly be extinguished. Here, then, is plainly an important and difficult problem for solution. We know that the fire-damp of the miner is likely to show itself wherever new openings are made in the coal-beds, that, indeed, in some mines it is constantly escaping; we know that it is very dangerous to have unprotected flames in the mines, and we know that the flames must be there, and must communicate with the air in order that they may continue to burn. Is it possible to avert the danger? This question had frequently been asked, we may be sure, before it was finally answered. In the early part of last century a number of gentlemen residing in the colliery districts of England, being fully aroused to the great dangers connected with the work of the miner, formed themselves into a committee to investigate the subject. They succeeded in 1815 in engaging the services of Sir Humphry Davy, who was then at the height of his popularity, and he at once began a series of careful studies, which resulted in a satisfactory solution of the problem. He invented the "safety lamp," which, in spite of numerous rivals and its admitted imperfections, is still in use, having undergone but slight modifications since it was perfected by him (Fig. 3). This lamp is a very simple piece of apparatus, but, in order that we may thoroughly understand it, it will be necessary to inquire into a few principles upon which its success depends.

FIG. 6.—MINER EQUIPPED WITH SAFETY LAMP AND PICK.

In the first place, then, we must bear in mind what a flame is. The lamp burns, as we say. That is, the oil with which the lamp is filled is drawn up by the wick; it is then heated and converted into gas, and the gas burns. Now a flame, no matter where we may meet with it, no matter from what it may be formed, is always *a burning gas*. The gas may be furnished directly, as in the case of our ordinary illuminating gas; or it may be made from a liquid, as in the case of lamps; or it may be made from solids, as in candles, or in the burning of a piece of wood or coal; but in all these cases the material is converted into a gas, or a mixture of gases, before the flame appears. In order that a gas may burn, it must first be heated to a certain temperature, called its *temperature of ignition*. This is equally true of everything capable of burning. Take a piece of wood, for example. We know that this

wood must be heated to a high temperature before it will burn, and then the whole piece does not burn at once. The burning begins at the heated point, and from this point heat enough is communicated to the parts immediately adjoining it to cause them to burn. These, in turn, heat up the succeeding parts, and so on, until the entire mass is affected. We know how difficult it is sometimes to get a large piece of wood to burn. This is due to the fact that we cannot get a large enough part of it heated up to the burning temperature to communicate the requisite heat to the rest. If we cool down any burning body below its burning temperature, the burning necessarily ceases.

By means of a few simple experiments we may illustrate these facts with a flame. The flame of an alcohol lamp will answer the purpose, but a gas flame from a Bunsen burner, such as is commonly used in laboratories (Fig. 7), is better. Both these flames have the one property in common, that they do not deposit soot upon objects placed in them. Now light the gas, and bring down upon it a piece of brass or iron wire gauze. A piece four or five inches square may be held at one corner in the hand. It will not grow too hot during the experiment. Although the amount of gas which escapes from the burner is the same now as before the gauze was placed over the flame, there is no flame above the gauze. We may even press the gauze down very near to the burner without the appearance of any flame above it (Fig. 8). But if we apply a lighted match to the upper part of the gauze, a flame appears immediately, and continues to burn, the gauze now having no perceptible influence on it.

FIG. 7.—BUNSEN BURNER.

FIG. 8.—FLAME DOES NOT PASS THROUGH METAL GAUZE OF CLOSE MESH.

The temperature of the gauze, which is a good conductor of heat, does not reach the ignition point of the gas. Thus, although the gas passes through, the flame does not. (See also Fig. 9.)

If, on the other hand, the gauze be held about two inches above the burner before the gas is lighted, a light applied above it will cause a flame to appear above but not below it (Fig. 9), while if the light be applied at first below the gauze, the flame will appear below, but not above it. In either case the flame may be made continuous by lighting the gas above and below the gauze.

Or, further, a spiral of wire may be so introduced into the flame of an alcohol lamp (Fig. 10) as to extinguish it, though the spiral plainly does not act as an ordinary extinguisher, for it cannot exclude the air. Thick copper wire is well adapted to the purpose. It should be quickly introduced.

How shall we explain these simple facts? It can be shown that they all depend upon the cooling of the gases. The wire gauze

placed in the flame conducts off a certain amount of heat, and is not at first as hot as the flame, hence that portion of the gas which passes through the gauze is cooled down slightly below its temperature of ignition, and cannot burn ; but if we light it—that is, heat it up to its temperature of ignition—then it furnishes the necessary heat to light those portions of gas which afterwards pass through the gauze. A similar explanation, of course, holds for the second case mentioned, viz. that in which the flame is above the gauze. There is not enough heat conducted through the gauze to set fire to the lower column of gas. Similarly, the alcohol flame is extinguished because it is cooled down by the spiral.

We have thus given the commonly accepted explanations without giving any proof of their correctness. If they are correct, then it must be only necessary to heat up the gauze in the first experiments and the spiral in the last to prevent the effects described. This can easily be tested. If the gauze remain long enough in the flame to become heated up to the temperature of the flame, the latter strikes through. Or if the gauze be hot enough when brought down upon the flame, no effect is produced. So also if the copper spiral be heated before it is introduced into the alcohol flame, it does not act as an extinguisher. A great many other experiments might be described proving the same thing.

FIG. 10.—A COIL OF COPPER WIRE WILL PUT OUT THE FLAME OF A LAMP IF LOWERED INTO THE FLAME.

This is caused by the wire lowering the temperature of the flame. A glass rod wound about with coils of copper wire will serve the same end.

FIG. 9. — DEMONSTRATING THAT INFLAMMABLE GAS CAN PASS THROUGH GAUZE, ALTHOUGH THE FLAME DOES NOT, EXCEPT IN CASES WHERE MECHANICAL VIOLENCE IS USED.

It has been found, further, that metallic tubes of small calibre, as well as gauze, prevent the passage of flame. Tubes one-fifth of an inch in diameter and an inch and a half long are sufficient. Or a bundle of wires placed in a larger tube, in such a way as to fill it as far as possible, forms an apparatus which has the same power. Such a tube is sometimes used for the purpose of safety in connection with explosive mixtures of gases. It being impossible for flame to pass through it, of course its attachment to a vessel containing an explosive mixture will diminish the danger. In short, anything consisting of metal, in which the apertures are small, will effect the cooling of gases which pass through, and if the gases are burning on one side of the apparatus the flames are extinguished in passing through.

Davy's safety lamp, as we know, is to

prevent explosions of mixtures of fire-damp and air, and still permit the use of lights in the mines. When a flame is applied to such a mixture, there is an instantaneous burning of the mass, the burning temperature being very rapidly communicated through the mixture. The elevation of temperature which accompanies the burning causes a sudden and great expansion of the gases ; and the rapid burning and expansion constitute the explosion. Gunpowder explodes in a similar way. It requires but a spark to decompose the smallest particle of the powder, and the action is then communicated with great rapidity through the mass. When it decomposes, it is converted largely into gases, and the volume is enormously increased. In both cases the main act is that of burning or combustion, and this takes place so readily because the substance burned is intimately mixed with the substance which furnishes the oxygen necessary for the combustion. In the mixture of fire-damp and air, it is the former which burns, and the latter which furnishes the oxygen. In the gunpowder, carbon (charcoal) and sulphur, burn, while the oxygen is furnished by the saltpetre, the third constituent.

The explosion, then, is a rapid combustion. But we have seen that a gas must be heated up to a certain temperature before it can burn, and if we can prevent the mixture in the mine from becoming heated up to this temperature at any point the explosions can be averted. The wire gauze may be brought to our assistance. The first thing that naturally suggests itself is to surround the lamp flames with gauze. Let us see how this would work. Suppose the flame thus protected should be introduced into the explosive mixture, what would take place? The gaseous mixture would, of course, pass without hindrance through the gauze, and come into contact with the flame. That portion of gas inside the gauze envelope would explode, and perhaps a number of such small explosions might take place. These would distinctly give the word of danger to the miner. But though the explosions take place within the gauze, the heat necessary to ignite the large mass without is not communicated through it, and the awful results are avoided. This certainly sounds well, but it must be remembered again that it is one thing to speculate on a subject, and often quite another to prove the correctness of the conclusion drawn. In this case, fortunately, the reasoning is correct. A candle or lamp, the flames of which are protected in the manner described, may be lowered into a vessel containing explosive mixture without danger of explosion. The experiment can be easily tried in the laboratory, and has frequently been made. There is no doubt as regards the result, and hence the problem which confronted us a few minutes since is apparently solved, and by the simplest means. Minor questions may now come up as to the most convenient form of the lamp, etc., but the problem is essentially solved.

When we consider the simplicity of the lamp we fail to obtain a just idea of the amount of labour which had to be gone through before success was achieved. It is fascinating to turn to the paper of Davy,* in which he gives an account of the experiments he undertook in working out the problem of the safety lamp. We can become familiar with the workings of his mind, and we cannot fail to admire the beauty of his methods. As we read, our own thoughts keep pace with those of the writer, until we can almost imagine ourselves the successful inventors.

The lamp, in its perfected form, only requires a careful workman—that is, one who will always think to put his lamp out before he opens it. But workmen become accustomed to danger, and after a time scarcely give it a thought. To prevent accident from thoughtlessness, it has been

* "Philosophical Transactions of the Royal Society of London," Nov. 9th, 1815.

found necessary to add some attachments to the lamp. These are mainly—first, one which makes it possible to light the lamp without opening it ; and, secondly, one which makes it impossible to open the lamp without first extinguishing the flame.

It should be mentioned here that at the same time that Davy was engaged in his work George Stephenson, then an engine-tender in a colliery in Northumberland, was studying the same problem, and that he also succeeded in inventing a safety lamp, which, in principle, is identical with that of Davy. This lamp was used at the Killingworth pits in 1815, that is, in the same year in which Sir Humphry Davy's communication was made to the Royal Society ; it was a modification of the Stephenson lamp, the characteristic feature of the latter being the glass cylinder. But it is unnecessary to go into details on this point, those curious regarding the matter are referred to Dr. Smiles's "Life of Stephenson," pp. 157, 169, 171, 176.

Dr. W. Reid Clanny, of Sunderland, really claims the credit of having made the first lamp which will burn in explosive gases, but, although he was two years ahead (1813) of both Davy and Stephenson, his lamp did little more than demonstrate a principle. The flame of the lamp drew its air supply through water, and the contrivance, although ingenious, was not suitable for everyday use. The "Clanny" lamp of later days must not be confounded with this, for it is quite a different contrivance, and both workable and useful. The Marsaut lamp, invented by M. Marsaut, of the Bessèges Collieries, at Gard, in France, is a favourite in many quarters to-day, and the bonneted Muesele has its adherents. The Thorneburry safety lamp, patented in 1889, burns high-flash petroleum of great illuminating power, and is in fact superior to older forms in this respect.

Probably the lamp of the future, however, is a portable electric lamp ; for as air is rigidly excluded from this there can be no danger from gas currents of (comparatively) great velocity, as there is with the ordinary flame lamps. In illuminating power these electric glow lights would be easily first, but they would not serve the purpose of fire-damp detectors, as the Davy, and the Geordie, and the others would. Electricity has already been turned to account in lighting up the galleries and shafts of coal pits, and it may be confidently predicted that it has only begun to be useful in this direction.

THE ANATOMY OF A LONDON FOG.

By ARTHUR H. BELL.

(Assistant, Meteorological Office, Victoria Street, S.W.)

NOTWITHSTANDING the fact that the sulphurous and carbonaceous particles in a fog are said to have a deodorising and disinfecting action, it is probable that there is nothing most large towns and cities would sooner be without. Indeed, so great a nuisance have these fogs become that they have at last been taken in hand by the London County Council, which, with the assistance of the Meteorological Office, has recently completed certain systematic investigations with the object of seeing what can be done to mitigate, or at least to anticipate, the visitations of these depressing phenomena. In short, their favourite haunts have been discovered, and the seasons and hours when they are most active put on record, the idea being to find out whether there is any way of foretelling on what days these fogs may be expected to arrive. Railway, gas, and electric light companies would all much like to know when a strain was likely to be put on their resources, and they, as well as the private individual who so often has to grope his way through some smoky, brumous, sun-obscuring veil, will be glad to hear that at last these fogs have been scheduled as a nuisance. Thus formally arraigned, it may be that the "London particular" has received notice to quit.

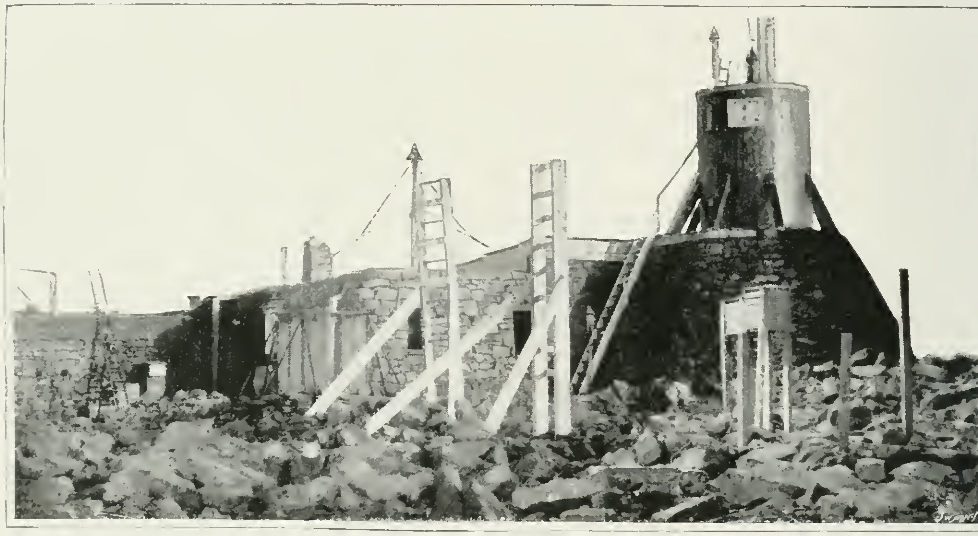


FIG. I.—THE OBSERVATORY ON BEN NEVIS IN SUMMER.

But, apart from its unpleasantness, a fog is a very interesting thing. It may, moreover, safely be said that if meteorologists could only become thoroughly acquainted with the anatomy of a fog they would have gone a long way towards solving many other interesting problems connected with the weather. A fog in its simplest form is really very unsophisticated, and it is only when it goes through its life's history in a town

that its early simplicity becomes obscured. In its most primitive state, a fog is but a cloud resting on the ground: it is mainly made up of pure vapour, and is quite innocuous. Commonly such a fog is called a mist, the mists which appear in the country affording the best illustration of the kind of thing that is meant. These mists are, as a rule, short-lived, and the sunbeams very quickly put them to flight. But the fog and the mist are, however, very near relations of the clouds, and many of the forces which combine to make the latter are to be found actively engaged in building up the former (*see* Figs. 1, 2, and 3).

Now it is to be observed that the aqueous vapour suspended in the air is very susceptible to changes in temperature, and if it is cooled below a certain point some of this vapour spills over, as it were, or, in other words, it is condensed. There are, moreover, many ways by which the cooling may be brought about, one of the most obvious ways, perhaps, being when a mass of warm, moist air flows against the side of a cold mountain. When this occurs, a cloud at once forms, this condensation of moisture being sometimes called a mountain mist. But in order to produce such a mist it is by no means necessary that the air should flow against a solid body, for in its journeyings through the atmosphere the vapour encounters many things of a different temperature from itself. Supposing, for instance, that the air passes over a lake or a river whose surface is of a lower temperature than that of the air above it, all the conditions for manufacturing a fog or a mist will be at hand. It is also to be observed that the same thing will happen when a cold current of air passes over warmer water, the essential thing being that the two colliding surfaces are of a greatly different temperature.

FIG. 2.—THERMOMETER BOX AND LADDERS AT THE SAME OBSERVATORY COVERED BY FOG CRYSTALS.

The effects of water, in this respect, on the atmosphere are perhaps best illustrated by referring to the Banks of Newfoundland, which time out of mind have been the home of persistent fogs. Water, it is to be remembered, is very slow to change its temperature, so that although it may perhaps become warmed

by the summer sun it does not at once lose this heat when the cooler days come. Hence during the autumn months it often happens that the sea is of a higher temperature than the air in contact with it: a fact, it may be noticed in passing, that explains why it is that during the autumn and early winter the climate of seaside places is so much more equable and mild than that of places having an inland or continental situation. The sea, then, owing to this curious characteristic, has great facility in producing fogs, and it is to this circumstance that the autumn and spring fogs which appear over the sea are due. On the Banks of Newfoundland, owing to the effects of the Gulf Stream and the icebergs, there are nearly always marked contrasts between the temperature of the sea and the temperature of the air, and hence it is that the aqueous vapour here finds one of its most fitting opportunities for producing some of its most noteworthy fog effects.

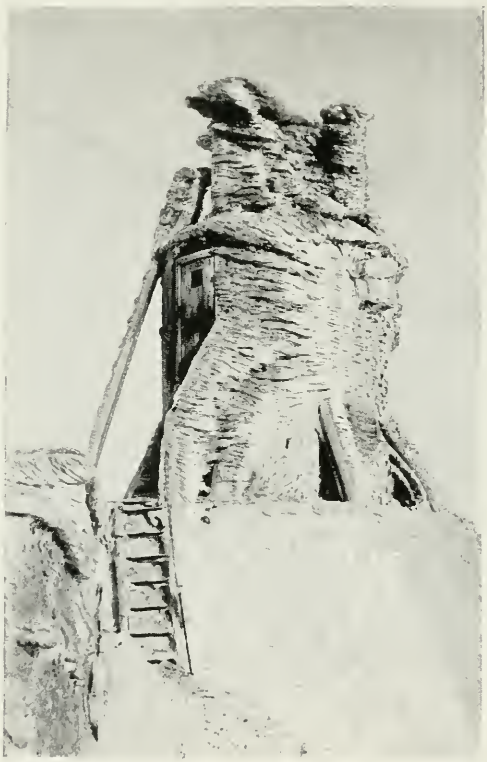


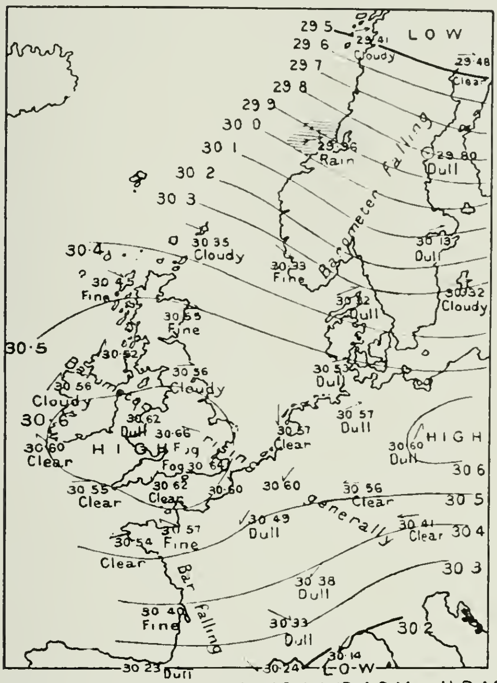
FIG. 3.—THE TOWER OF BEN NEVIS OBSERVATORY SWATHED BY FOG CRYSTALS.

But not only are there contrasts between the air and the surface of land and water, but similar differences are to be noted in the currents of air themselves. It is, indeed, to this fact that the majority of fogs are due. Fogs, moreover, it will have been observed, occur at times when there is little or no wind, or, better still, when the breezes are of moderate force and very variable in direction. In such circumstances as these many of the air currents radiate their heat quickly and loiter in the atmosphere like a cab-driver seeking a fare, so that any warmer current that comes slowly drifting along is arrested and made to deliver up or condense any vapour that it may carry with it. This practically windless atmosphere, it may be mentioned, is also very favourable for the formation of hoar-frost, which so often in the winter months accompanies some of the densest fogs; the fact is that fogs, dew, hoar-frost, and other children of radiation produce their most elaborate effects in a quiet atmosphere. Now in all large towns where there are open squares and parks with long streets, down which the air is conducted as down a funnel, all the conditions are present for producing these variable currents that are the life and motive force of every fog. Around many of these open spaces the air, moreover, cools rapidly, while through the neighbouring streets the air is brought as through a conduit to the meeting-place of the zephyrs, so that the whole space literally becomes a congested area. Contrasts, therefore, as regards temperature are produced by these arriving breezes, so that the vapour condenses and a first class fog results. Anyone acquainted with London, for example,

will have no difficulty in calling to mind many similar spots—such as Hyde Park

ANTICYCLONIC 25 NOVEMBER 1901

8 A M



MODERATE FOG 6 A M TO NOON AND 4 P.M – 11 P.M.
TEMPERATURE AT BRIXTON AT 8 A M 30°
(FIG. 4.)

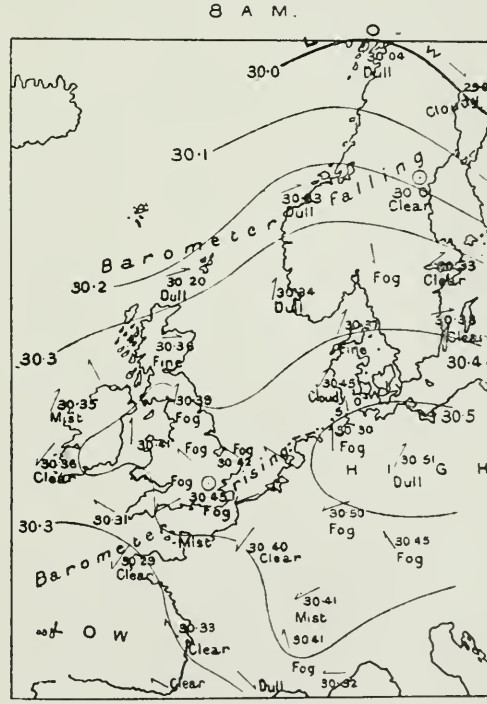
Corner, for instance—that are notoriously foggy.

But in respect of town fogs the most peculiar feature is their persistence—a circumstance due, as is well known, to the fact that they are not made up of pure vapour, but are all too frequently composed out of various deleterious substances. Sulphur, carbon, and ammonia are the things most commonly found when a sample of town air during foggy weather is analysed, and since such particles appear in myriads they attract moisture to themselves, and so give an opaqueness to the fog. It is a commonplace of meteorology nowadays to say that clouds, rain, dew, hoar-frost, and fog cannot spring into being unless there is first of all a dusty nucleus upon which the condensing moisture can settle. Indeed, if it were not for these dusty atoms, rain would be perpetually falling on the earth, but since they are everywhere present they serve as resting-places for the vapour and so keep it buoyed up in the air.

Even in a country fog these dusty particles are always present, but, of course, in diminished numbers. The number of these particles has been estimated by means of an instrument designed by Mr. John Aitken; while another kind of apparatus has served to enumerate the drops of moisture themselves. This latter instrument on one foggy occasion showed that tiny drops of moisture were condensing out of the

A HIGH RIDGE 5 NOVEMBER 1901.

8 A M.



THICK FOG ALL DAY
TEMPERATURE AT BRIXTON AT 8 A M 34°
(FIG. 5.)

air in such numbers that 80,000 of them were settling on every square inch of surface. Now the question might be asked, Why is it that such a steady descent

of moisture does not submerge everything in a deluge? But the answer is found in the fact that these droplets are exceedingly small, so that they evaporate as soon as they are formed. Some fogs literally rain themselves away, as it were, in this manner, and there is a certain reason why they do so, this reason upon examination and experiment proving to be dependent upon an interesting and peculiar action of the atoms of dust.

Supposing, for instance, that there are only a comparatively small number of these particles in the air, it will be seen that when moisture commences to condense, it finds, so to speak, but limited accommodation. As a result, each atom of dust is soon loaded up with moisture, and becomes very heavy, so that it promptly falls to the ground, being joined in this descent by countless numbers of its fellow particles. When, therefore, dusty nuclei are scarce, as they commonly are in country places, the fog or mist has but a short life, and is quickly dissolved, coming to an end simply by its own weight.

Bearing these elementary principles in mind, the important part these dusty atoms, whether made of carbon or of sulphur, play in giving permanence to a town fog will be realised. In this case they loiter in the atmosphere in such vast numbers that the vapour as it condenses finds a ready foothold, and there are, it might almost be said, as many nuclei as there are particles of moisture. The obvious result is that there is hardly enough vapour to go round, so that each dusty loiterer receives but a tiny load and is accordingly able to remain floating in the air. That the sun-obscuring effects of the carbon and sulphur atoms are greatly increased by the moisture which settles on them goes without saying; but it should in passing be observed that the opaqueness of a town fog is due, not so much to the size of these particles, as to the circumstance that their number is so great. A piece of glass, for example, in its ordinary state is quite transparent, but if it be pounded up into an infinite number of small pieces it at once becomes opaque. Something of this kind happens in a town fog, for when the particles of carbon are large the light creeps through the interstices, as it were; but let them multiply, and the result is an opaque curtain that obscures the sun and turns day into night.

Nor is this all. It is a matter of common observation that a film, say, of coal-tar will greatly retard evaporation of moisture from any water surface. Now in all town fogs it has been discovered that the moisture as it forms into fog-drops becomes quickly coated with such a film as this, and it will be understood that this covering prolongs the life of the drops and gives permanence to the fog. Moreover, many of the atoms of sulphur and carbon have a great affinity for moisture, which they absorb, so to speak, into their system, parting with it only under extreme compulsion. What with the protecting film and this intense avidity for moisture, it is not therefore surprising that a strong combination of circumstances is required to disintegrate and disband a fog built up of particles so well equipped for maintaining their position in the air. The atmosphere, moreover, during foggy days is very like some Brobdingnagian vessel filled with chalky water, for the floating atoms are continually settling downwards until the lower strata of the atmosphere become thoroughly congested. A thick protecting canopy is therefore built up, and beneath this screen the inert dusty atoms may for days defy the sun to move them on.

From time to time experiments have been made with the view of determining the chemical composition of a London fog, some of the most interesting ob-

servations having been made by Dr. W. J. Russell, F.R.S. The samples of air that he tested were secured at St. Bartholomew's Hospital, in the City of London. One of the most objectionable things about a London fog is of course the carbonic acid that enters so largely into its composition (Fig. 6). and the pared with other places, this figure is good. Thus at Manchester it is 4·03, at Perth 4·14, at Glasgow 5·92, and at Grasmere 3·13. A mean of several sets of observations gives the number 3·036, which may be taken as representing the amount of carbonic acid in the purest air. Even compared with this figure,

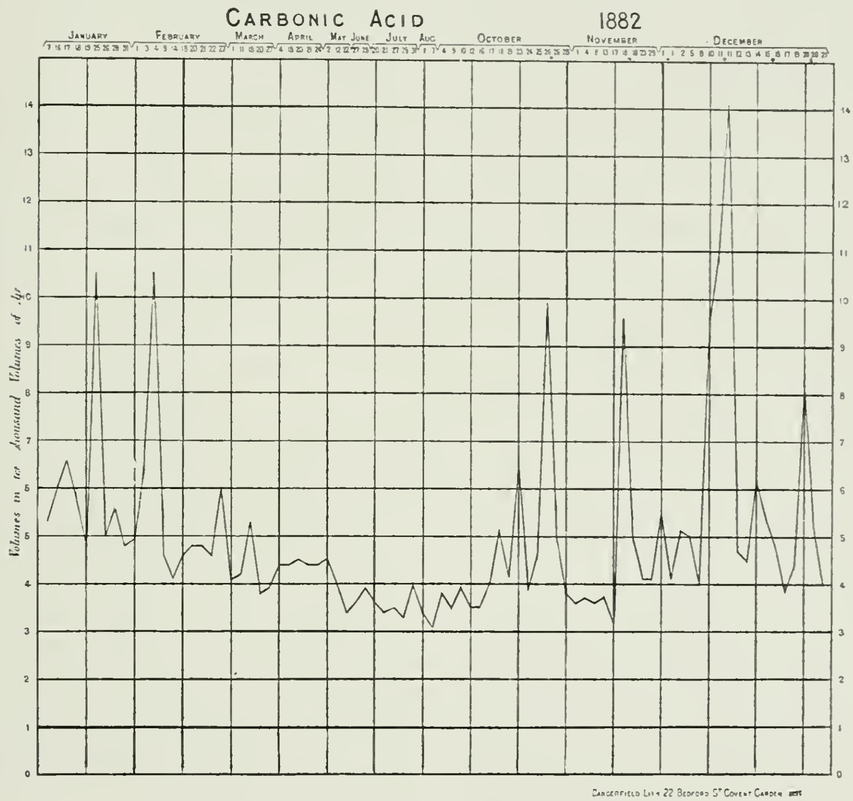


FIG. 6.—SHOWING THE VARIATIONS OF THE AMOUNT OF CARBONIC ACID GAS IN LONDON AIR.

(From the Weather Reports of the Meteorological Office.)

experiments in question were on one occasion mainly confined to observing the variations that daily occurred in this unpleasant substance. By so doing it was possible to discover the increase that was to be credited to the fogs. From these experiments it would appear that in the City on an ordinary day the amount of carbonic acid in the air is not above four parts in 10,000 of air. Now, compared London on a fine day has a fairly clean atmosphere. Curiously enough, Dr. Russell found the purest air in London on Bank Holiday, for both on Whit Monday and on the August Bank Holiday the amount of carbonic acid fell to 3·3.

Turning now to the figures that were obtained during foggy weather, we immediately find that they go up enormously. Thus during one very dense and prolonged fog the amount of carbonic acid in

London went up to the high figure of 14·1. Taking the figure given previously as representative of pure air, it will be seen that a fully equipped "London particular" can increase the normal supply of carbonic acid by more than three times and a half. Occasionally it is noticed that there is an increase in the carbonic acid that is not due to fog, but it is generally found that at such times the weather is gloomy and the air still. In this connection also it may be mentioned that another series of experiments was conducted for the purpose of discovering the amount of organic matter and of sulphuric acid present in London air during different kinds of weather (Fig. 7).

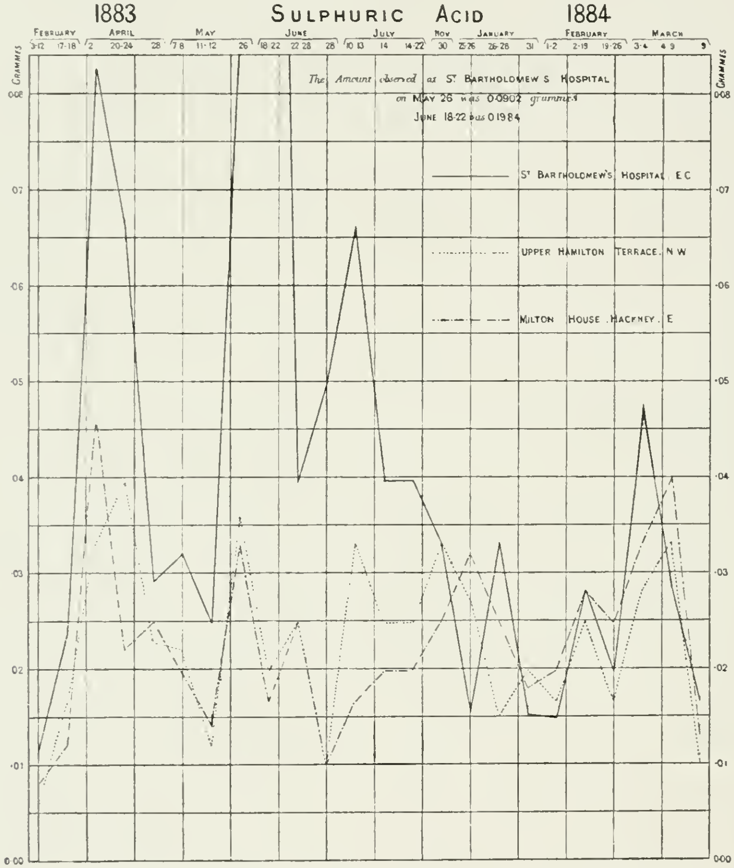


FIG. 7.—THE VARIATIONS IN THE AMOUNT OF SULPHURIC ACID IN LONDON AIR.

(From the Weather Reports of the Meteorological Office.)

The organic matter was ascertained by determining the amounts of carbon and nitrogen respectively in grammes per 1,000 cubic feet of air. The little table given below shows how all these deleterious things increase during foggy weather, and since the figures are for fair, dull, and foggy weather an easy comparison is possible. The table is as follows:

	Carbon.	Nitrogen.	Sulphuric Acid.
Fair weather ...	·0033 ...	·0002 ...	·0128
Dull weather ..	·0101 ...	·0002 ...	·0319
Foggy weather ...	·0239 ...	·0005 ...	·0420

From these and similar figures it is clear, therefore, that a London fog is built up very largely of carbon and

sulphur substances which come almost entirely from coal. It has, indeed, been said that fogs are greatly due to the domestic fires, and not so much to the factory chimneys. Christmas Day, for instance, a time when the domestic chimney is in full blast, has been associated with some notable fogs. It has further been pointed out that there is a ready way by which anyone may tell when fog is most likely to visit his neighbourhood. All that is required is a map from which it may be discovered in what direction the greatest length of chimney-pots lies. Then, other things being favourable, when the wind is observed to be blowing along this line, fog may be successfully predicted.

The forecast may be made still more accurate if the observer keeps a watchful eye upon his barometer. The weather charts show that the worst fogs are associated with a high barometer, or, as the meteorologists would say, with anti-cyclonic conditions. With such conditions there is little or no wind, and, as already seen, this is the weather in which fogs thrive. In other words, the barometric gradients are slight, the temperature at the same time being low. During cold weather, therefore, when the Meteorological Office announces the approach of anti-cyclonic weather, it is always as well to be prepared for a fog. The charts shown in Figs. 4 and 5 illustrate the appearance of a weather chart during a spell of excessively foggy weather.

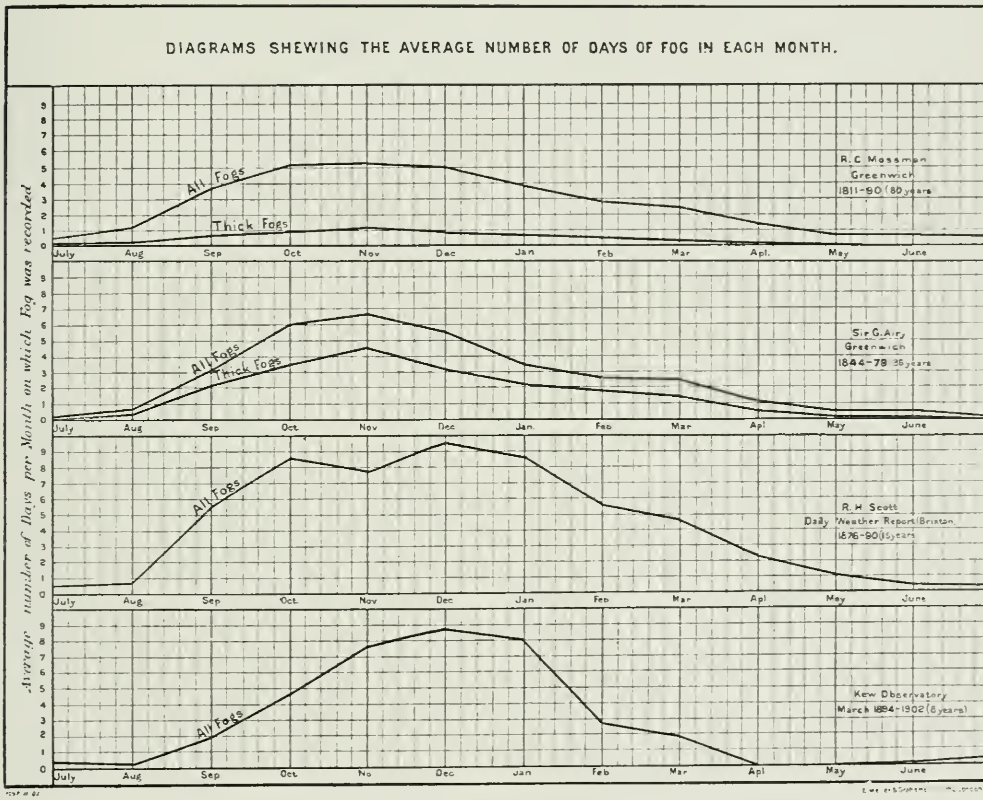


FIG. 8.—FOGGY DAYS AND WHEN TO EXPECT THEM.

(From the London Fog Enquiry Report (1901-2) to the Meteorological Council by Captain Alfred Carpenter, R.N.)

In many laboratories fogs have been produced by artificial means, and it is, indeed, in this way that fogs have been largely studied. By using glass globes and drawing in air of various temperatures, and by injecting dust of many descriptions, the anatomy of town fogs may be studied at leisure and without the attendant discomforts of the real article. All the phenomena previously described may be thus produced, and it is such experiments that have given sanction to the ideas concerning the part played by the atoms of dust that are nowadays entertained by most meteorologists. And not only are the fogs thus reproduced, but they are further experimented upon when they have been successfully brought into being. Among other ways of dealing with them, they have been experimented upon with electricity, some curious results being obtained when a current of electricity is passed through the glass globe containing the fog, the results varying, of course, according to the material of which the fog is composed.

On one occasion, after treating the fog to an electric shock, it was found that all the dusty nuclei had been precipitated and the fog destroyed. Now among the various suggestions that have been made for getting rid of fogs—and they have been many—it may be supposed that the theorists have from the starting point of the above experiment arrived at the conclusion that a fog could be moved on by shaking the carbon out of it by electricity. It has been seriously suggested that the electric shocks could be administered from captive balloons; but the scheme needs to be completed by a statement as to what should be done as regards clearing away the soot thus ejected from the atmosphere. If this scheme should be adopted by the County Council it is further possible that there would be trouble with rose-growers, to say nothing of the laundresses.

Recognising also that fogs are chiefly prevalent in calm weather, other enthusiasts have suggested that these baneful visitors might be driven off by raising a wind. This in several ways has ever proved a difficult business, but, as regards fogs, the theorists have further said that this purpose might be effected by a series of aërial bombardments. Having this purpose in view, the promulgators of this scheme have cast envious eyes on the out-worn and disused cannon which serve a more or less ornamental purpose in many of the public parks. If this should prove to be the adopted scheme, it will doubtless happen, on the approach of an incipient fog, that a fusillade will commence in all the County Council open spaces, and under the impact of the hypothetical breezes thus produced the fog may fail to come to maturity.

Yet other schemes advise the building of huge bonfires, such as would create upward currents of air, on the wings of which, as it were, the fog would disappear. Now, seeing that fogs have a way of making their most perfect demonstrations on or about November 5th, it is probable that with a certain juvenile section of society this proposal would be carried with acclamation. But, when all is said and done, it will, after all, be found that the fogs will be dismissed only by a closer scrutiny of the coal cellar; for, as already seen, the anatomy of a fog is principally built up of carbon, and possibly, when all cooking is done by electricity, there will be nothing for the fogs to thrive on, and they will cease to be.

STONE-LILIES AND FEATHER-STARS.

THE stone-lilies belong to a somewhat varied assemblage of animal forms, which may be described by the general term of "limestone-builders." Many limestones consist almost entirely of the remains of these beautiful animals, which are known to naturalists as Crinoids. The Greek word *krinon* means a lily; and long before the adoption of the term Crinoidea for this class of animals, the name Encrinites—in which the same root is traceable—was employed to describe their fossil remains. The earliest author who systematically treated of these remains was the celebrated Agricola (A.D.

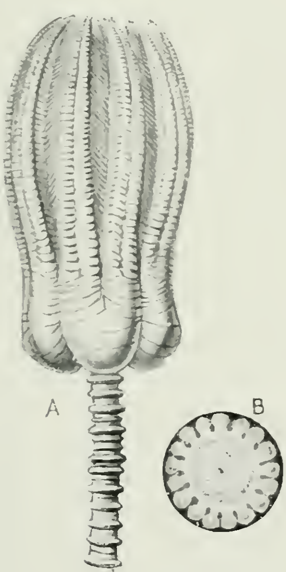


FIG. 1.—LILY ENCRINITE (*ENCRINUS LILIIFORMIS.*)

A, the whole encrinite; B, a joint of the stem.

1530), though, from the manner in which he speaks of them, it is evident that they had long attracted the attention of naturalists, and that the names *Trochites*, *Entrochus*, and *Encrinus* had found their way into general use.

The first was applied to the separated stem-joints, which have since been known as "St. Cuthbert's beads," a name familiar to the readers of "Marmion." *Entrochus* was used to denote a larger piece of stem, consisting of several united joints, such as one may find without difficulty in the limestones of Clifton Down, Wenlock Edge, and elsewhere. The last name, *Encrinus*, was applied to the lily-like remains, which consisted of a cup supported on a stem and giving off ten or more arms. This name has gained a permanent place in scientific nomenclature, as denoting one particular genus of the fossil Crinoidea, the commonest species of which is the well-known "Lily Encrinite," from the Trias of Germany (Fig. 1).

The mutual relationship of the three kinds of fossil remains mentioned above was not recognised till more than a century after the time of Agricola, and even then their real nature was misunderstood. Fossil Crinoids were described as "certain stones figured like plants, and by some esteemed to be plants petrified." Another writer speaks of their remains in the Carboniferous Limestone of Somersetshire as "rock-plants growing in the lead-mines of the Mendip Hills." Observing men, however, did not altogether agree as to which way up these rock-plants grew: for while some authors believed the body or cup of the Crinoid to be the base of the stem, and regarded the arms as radiating and subdividing roots, others considered that the more or less branching roots of the "Pear Encrinite" (Fig. 8) really belong to the body, and not to the lower part of the stem. By other writers

the cups were taken for petrified flowers or fruits, and the stems thought to be the backbones of fishes.

The credit of pointing out that the Crinoidea, far from belonging to the vegetable kingdom, are true animals, closely approximating in structure to the existing types known as sea-stars, is due to Edward Llhuyd, who was keeper of the Ashmolean Museum at Oxford at the end of the seventeenth century. Not only did he refer these remains to the same group with the sea-stars, but he even pointed out the "feather-star" (Figs. 2 and 3) as the particular form of sea-star to which the fossil Crinoidea are most closely allied.

The "feather-star" differs considerably from the other star-fishes, both in its external appearance and in its mode of life. As in the Echinoderms generally, there are five rays corresponding to the five arms of the star-fish; but each of these five rays may fork from one to seven times, so that the number of arms sometimes reaches two hundred or more.

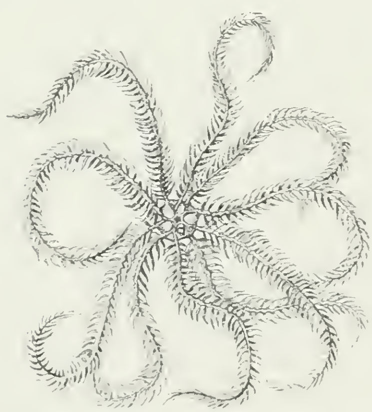


FIG. 2.—THE ROSY FEATHER-STAR (*COMATULA ROSACEA.*)

In those of our own seas, however, such as the rosy feather-stars, *Antedon* or *Comatula rosacea* (Fig. 2), there are rarely more than ten arms. These arms are supported by an internal skeleton of limestone joints placed end to end, and are closely fringed with smaller jointed appendages, which spring from them like the barbs from the quill of a feather. This feature sufficiently accounts both

FIG. 3.—A YOUNG ROSY FEATHER-STAR IN THE STALKED OR "PENTACRINOID" STAGE.

for the popular and for the scientific names of this animal. It will be remembered that the ordinary star-fishes, brittle-stars, and sea-urchins live with their mouths downwards, and crawl about on the sea bottom in search of food by the aid of their numerous sucking feet. The feather-star, however, lies on its back with its mouth upwards, and has a number of little jointed hooks fixed in the middle of its back, by which it can anchor itself to stones and sea-weeds. It detaches itself occasionally, and swims about for a while with a peculiarly graceful alternating movement of its arms, eventually settling down again in its previous attitude. The mouth is in the middle of the upper surface of the body, and the arms are spread out around it. On the upper surface of each arm is a groove, which is lined by a vast number of those delicate little protoplasmic filaments that are known to naturalists as *cilia*. The con-

tinued vibratory movement of these "cilia" produces currents in the water that carry tiny food-particles—protozoa and diatoms —towards the mouth, where the grooves of all the arms meet (Fig. 4).

It must be remembered that Llhuyd's determination that the fossil stone-lilies are allied to the recent feather-stars was made without any knowledge of the fact that there are such things as living stone-lilies. The first of these known to science was not discovered till fifty years after Llhuyd wrote, and even then its true nature was misunderstood. Eminent naturalists, like Linnæus, Lamarck, and Cuvier, considered these recent sea-lilies as zoophytes, allied to the sea-pens, sea-firs, sea-shrubs, and the clustered sea-polype, while the feather-stars were thrown back again by them among the other star-fishes. It was not till the year 1821 that Mr. Miller, a German naturalist, residing in Bristol, showed clearly that the feather-star is essentially similar to one of the old stone-lilies or to a recent sea-lily, except that it has no stem. The general structure and the mode of life are identical in both. *Pentacrinus* is the type which was first known to science, one having been brought from the West Indies by a French naval officer in 1755, and placed in the museum of the Jardin des Plantes, at Paris, under the name of "Palmier Marin." This West Indian species (*Pentacrinus Caput-Medusæ*), which is represented at Fig. 4. differs considerably from *Pentacrinus maclearanus*, which was dredged by the *Challenger* from the depths of the Atlantic, and named after one of the officers on board by Sir Wyville Thomson. For more than a hundred years after the first *Pentacrinus* was brought to Europe these beautiful animals were excessively rare. Even as late as the year 1865 as much as £50 was paid for a single specimen. But the systematic exploration of the bed of the ocean by the dredging expeditions of England, America, and other countries has made them more abundant in collections, though not the less beautiful. They live in great forests on certain parts of the sea bottom, sometimes attaching themselves to telegraph cables. In other kinds, however, such as *Rhizocrinus*, the stem ends below in a spreading "root," and so fixes the animal in the ooze which covers the ocean bed.

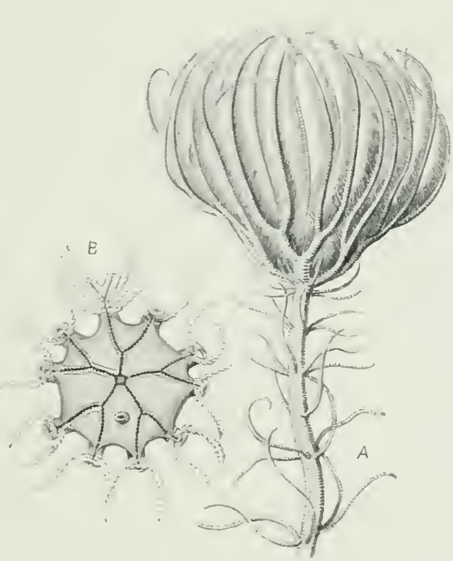


FIG. 4.—*PENTACRINUS CAPUT-MEDUSÆ.*
A, side view; B, disc, as seen from above. Note the grooves which convey the food to the mouth.

Like the feather-stars, they live with the mouth upwards, and the branching arms spread out so as to catch as many small particles as possible in the currents which sweep down the food-grooves towards the central mouth (Fig. 4).

The relationship between the feather-stars and the stalked sea-lilies is still closer than was imagined by Llhuyd and Miller, for the young feather-star is not free like its parent, but grows on a stem (Figs. 3 and 5), from which it eventually detaches itself. In this stage of its development it is known as a Pentacrinoid larva, a name which expresses its resemblance

to the permanently-stalked *Pentacrinus*. This curious fact was discovered by Mr. J. Vaughan Thompson, and was confirmed five years later by the late Professor Edward Forbes, who was fortunate enough, when dredging in Dublin Bay, to find numbers of the Pentacrinoid young of the rosy feather - star in a more advanced stage than any that had ever been seen before. Some of them, indeed, were so far advanced that Professor Forbes was actually able to "see the creature drop from its stem and swim about, a true feather-star." The severance occurs between the second stem-joint and the top one, which becomes an important part of the mature animal, for it bears the hooks by which the creature is able to fix itself to sea-weeds, zoophytes, etc. In some cases as many as thirty of these hooks may be developed before the animal parts from its stem and commences its new mode of life.

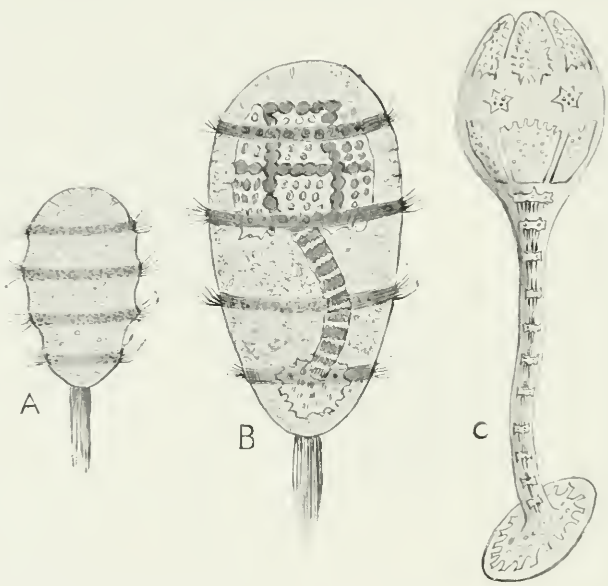


FIG. 5.—THREE STAGES IN THE DEVELOPMENT OF A ROSY FEATHER-STAR.

A, larvæ just hatched; B, the limestone plates appear; C, Pentacrinoid larvæ. Note the swelling at the base where the Pentacrinoid is "attached." The mouth is in the centre of the globular expansion at the top; no arms have yet appeared.

The gradual development of the stem is a very interesting process. The young of the feather-star leaves the egg as a little oval body about the thirtieth of an inch in length, shaped somewhat like a small barrel, and surrounded by four hoops of long vibratile cilia, with a still longer tuft of them at its hinder end (Fig. 5, A). By means of these cilia it swims about in the water. After a while slender limestone rods make their appearance near the front end, where the temporary mouth is situated, and by repeated forking and joining these rods give rise to ten plates of a delicate limestone network, which are arranged in two cross rings of five plates each (Fig. 5, B). Passing backwards from beneath the centre of the lower ring of plates is a series of delicate rings of limestone, which become supported later on by bundles of longitudinal rods forming inside them. The last of these bundles, at the hinder end of the larva, rests against a circular plate of considerable relative size. At this stage the larva has the form of a bent club or rod, with an enlarged head. The ciliated bands disappear, and it gradually loses its power of swimming, attaching itself to some stone or other solid substance by its base, the knob of the club being free (Fig. 5, C). This knob gradually becomes the body of the future feather-star, while the series of rings between it and the base of attachment develop into the elongated stem-joints of the Pentacrinoid. The enlarged head gradually becomes five-lobed, each lobe being supported by one of the upper rings of plates, and after a while the lobes separate like the petals of a

flower, so as to expose between them the opening of the permanent mouth. Around this mouth are five groups of three tentacles each, delicate tubular organs, which spring from a ring-shaped water-vessel in the lip.

The arms, which at this stage are quite undeveloped, now begin to make their appearance, sprouting outwards from between the two rings of plates, the upper one of which gradually disappears. Clawed hooks are pushed out from the enlarged uppermost stem-joint, which eventually separates itself from the rest of the stem, as described above.

The general anatomy of a feather-star or sea-lily is essentially the same as that of a common star-fish, allowance being made for the different position of the mouth in the two cases. Immediately within the ciliated groove of the Crinoid arm runs a nerve-cord, just as in the star-fish. Deeper still lies a blood-vessel, and then the water-vessel, which is relatively smaller and less important than in the star-fish, for the water-vascular system of the Crinoid takes no part in effecting the movements of the animal, like that of the star-fish does. Being more or less permanently fixed on its back with its mouth upwards, ready to take anything that comes in the way of food, the Crinoid has no need of sucking-feet to help it in moving about. But these organs, which are so important to the star-fishes and urchins, are replaced in the Crinoids by excessively delicate little tubes, the tentacles, in which the work of breathing seems to be carried on, oxygen passing through their walls from the water around them into that which they contain. All the water-vessels of the arms are lined by cilia, and communicate, like those of the star-fish, with a ring-vessel situated in the lip around the mouth. There is, however, a less direct communication between this vessel and the external water than is effected by the stone-canal of the star-fishes and urchins. But water is able to enter the body cavity through innumerable small tubular openings in its walls, which are lined by cilia, all working inwards ; some of these lead into the water-vascular ring, which is also in free communication with the body cavity by means of similar openings in its floor, so that it communicates readily with the exterior.

Here in the Echinoderms, therefore, we meet with an excellent illustration of a principle which is largely exemplified in the other sub-kingdoms of the animal world. There is one fundamental plan, according to which the various members of each sub-kingdom are constructed, but the details of this plan are worked out in different ways in the different classes of animals which together make up the sub-kingdom.

Neither the feather-stars nor the Pentacrinites can be said to enter largely into the formation of limestone, though there are some beds in the chalk of Bohemia which contain great quantities of the remains of the former. In certain parts of Germany there is an earthy bed of limestone a few inches thick, which is almost entirely made up of isolated joints of the stems, arms, and pinnules of Pentacrinites, collected together in enormous numbers. Here and there, too, both in this country (as at Lyme Regis) and abroad, large slabs of shaly limestone are found containing collections of fossil Pentacrinites, some of them very perfect, and remarkable for the great length of their stems. One specimen, found in Germany, has a stem the total length of which, as measured by its broken pieces, was found to be seventy feet, while others with stems fifty feet long are not uncommon. They must have presented a curious sight in their native seas, each with its long stem, on which was the crown of arms, not more than ten or twelve inches across when fully expanded.

The naturalists of the *Blake* expeditions in the Caribbean Sea succeeded in keeping some Pentacrini alive for two hours after their removal from the dredge. This was effected by "deluding the animals into the idea that they were in their native temperatures by putting them into ice-water." Previously to this, during the Hassler expedition of 1872, the late Professor Louis Agassiz was fortunate enough to be able to keep a little *Rhizocrinus* alive for ten or twelve hours, and he thus described what he saw: "When contracted, the pinnules are pressed against the arms, and the arms themselves shut against one another, so that the whole looks like a brush made up of a few long, coarse twines. When the animal opens, the arms at first separate without bending outside, so that the whole looks like an inverted Pentapod; but gradually the tip of the arms bends outward as the arms diverge more and more, and when fully expanded the crown has the appearance of a lily of the *Lilium Martagon* type, in which each segment is curved upon itself, the pinnules of the arms spreading laterally more and more as the crown is more fully open. I have not been able to detect any motion in the stem traceable to contraction, though there is no stiffness in its bearing. When disturbed, the pinnules of the arms first contract, the arms straighten themselves out, and the whole gradually and slowly closes up. It was a very impressive sight for me to watch the movements of this creature, for it told not of its own way only, but at the same time afforded a glimpse into the countless ages of the past, when these Crinoids, so rare and so rarely seen now-a-days, formed a prominent feature of the animal kingdom. I could see, without great effort of the imagination, the shoal of Lockport teeming with the many genera of Crinoids which the geologists of New York have rescued from that prolific Silurian deposit, or recall the formation of my native country, in the hill-sides of which, also among fossils indicating shoal-water beds, other Crinoids abound, resembling still more closely those we find in these waters." Had Professor Agassiz been an Englishman, he would have referred to the Wenlock limestone and to the Carboniferous limestone of Somersetshire, instead of the Silurian shales of Lockport; while he would have spoken of the Bradford clay and its pear-encrinites (Fig. 8) instead of the Jurassic Crinoids of Switzerland. The limestone of Wenlock Edge is of approximately the same geological age as the Lockport beds of America, and is very largely composed of the remains of Crinoids and Corals. In some parts of it the Crinoids are so abundant that it is spoken of as a Crinoidal limestone. Portions of this or of similar limestone beds are exposed at Dudley, Walsall, Woolhope, and Aymestry. That at Dudley is very rich in Crinoidal remains, and is the chief source of our museum specimens.

Ages after the close of the Upper Silurian period, Crinoids again played a very important part in the formation of a limestone. The great deposit of Carboniferous limestone which underlies the coal measures in South Wales and in Somersetshire is more than two thousand feet thick, and so highly fossiliferous that the whole of it may be said to have once formed parts of animals. The lowest five hundred feet of it consist chiefly of Crinoidal remains. In all parts of Europe where Carboniferous limestone occurs it is largely made up of the skeletons of stone-lilies. They are especially abundant in Belgium, in the neighbourhood of Liége, and are also very numerous in the Carboniferous series of America, as has been well described by Professor Dana. He has pointed out how there was a long period of limestone-making both in Europe and in America before any of our coal plants began their work of "bottling up the

sunlight" of ages now long past. There is proof, therefore, of the wide extension of the same geographical conditions, viz.

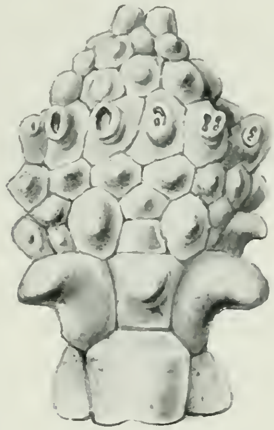


FIG. 6.—CALYX OF A PALÆOZOIC STONE-LILY (*ACTINOCRINUS KONINCKI*).

Notice the openings round the dome, near the top, at which food supplies enter.

an extensive submergence of the continental lands, as a prelude to the period of emergence and terrestrial vegetation that followed.

In the first half of the Upper Silurian there was a period when a sea, profuse in life, and thereby making limestones,

FIG. 7.—LILY ENCRINITE IN ITS MATRIX, SHOWING PLACES WHERE ARMS HAVE BEEN BROKEN OFF.

covered a large part of the interior continental basin of America, *i.e.* the region between the Appalachians and the Rocky Mountain chain. The same conditions were repeated in the early part of the Devonian age, and again in the Carboniferous there was a similar clear and open Mediterranean Sea, and limestones were forming from the relics of its abundant population. In the Upper Silurian period the living species were of a miscellaneous character. Brachiopods or lampshells, Crinoids, and Corals occurring in nearly equal proportions; but in the Devonian period Corals were greatly predominant, and in that of the Carboniferous Crinoids had as remarkable a pre-eminence. The most prolific locality for Crinoids in America is Burlington, in the State of Iowa. More than three hundred and fifty species have been found there, many of them in the most beautiful state of preservation.

FIG. 8.—PEAR ENCRINITE (*APIOCRINUS ROISSYANUS*).

These stone-lilies, which bloomed in the ocean depths when the earth was younger and our coal not yet formed, differ very considerably from the *Pentacrini* which inhabited the Liassic seas, together with the great sea reptiles, and have survived until the present time. In most of the older Crinoids the mouth was not on the external surface of the body, for it was covered in by a dome of rigid heavy plates (Fig. 6). But there were food-grooves on the arms, just as in the recent sea-lilies and feather-stars, and at the circumference of the dome were a number of openings, one for each groove, through which the food particles passed on their way towards the mouth.

The earliest representative of the more modern type of Crinoid in which the mouth is open to the exterior is the "Lily Encrinite" (Fig. 7), from the Trias of Germany, a very elegant and well-known species. In an old German book about the natural history of Altenburg, dated 1774, it is recorded that the Emperor of Germany once offered a hundred thalers for a good specimen of this stone-lily stars. Somewhat younger still are the "Pear Encrinites," which are so abundant in the Bradford clay (Fig. 8). In these Crinoids the body was considerably swollen, and the base of the long stem was furnished with a number of so-called roots, which served to fix the animal in the ooze covering the sea bottom. The pear-encrinites are represented in the chalk by a dwarfed and degraded type,

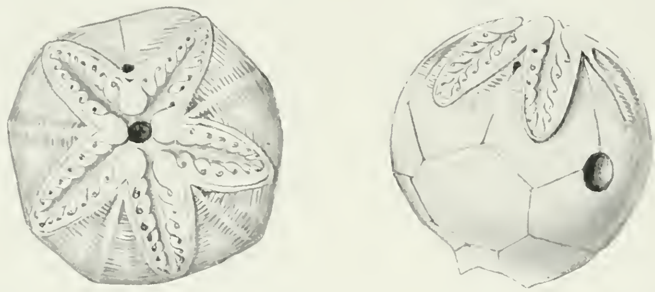


FIG. 9.—TWO VIEWS OF A "CYSTID."
A, top: B, side view.

attached to its stem and free from the matrix in which it had been embedded.

At the close of the period of the Trias there commenced the formation of the great Jurassic series, that takes its name from the Jura Mountains, where it is especially well developed. In the earliest member of it that occurs in this country, viz., the Lower Lias of Lyme Regis, we find the oldest representative of the *Pentacrinus* type. It has persisted ever since, living in the Jurassic and Cretaceous seas, and is now represented by several species which inhabit the Caribbean Sea and the median depths of the Atlantic and Pacific. In some localities they must be remarkably abundant, for during the cruise of the *Blake* in the Caribbean Sea no less than 124 specimens were captured by one "haul" of the dredge and its appendages.

Above the Lias formation is that of the Oolites, the lowest beds of which (Inferior Oolite of Gloucestershire) contain the remains of the oldest British feather- which has long been known as the "bottle-encrinite." It has been already pointed out that this degeneration was perhaps due to the reduced temperature of the Cretaceous seas, for it has continued since the time of the chalk formation, and has resulted in the appearance of the little *Rhizocrinus* that is so widely distributed over the Atlantic sea bed. The pear-encrinites seem to have fared worse during these bygone ages than the *Pentacrinus* type did, for the recent *Pentacrinidæ* resemble their ancestors much more than *Rhizocrinus* resembles the pear-encrinite. They are, however, smaller and less completely developed than the long-stalked forms of the Liassic seas.

The feather-stars of the present day also seem to be smaller than their predecessors which lived in the Jurassic and Cretaceous seas. Unlike the stalked Crinoids, which are almost entirely limited to deep water, they flourish best in the shallower waters nearer land, though small and poorly developed specimens have

been dredged at nearly 3,000 fathoms. Their geographical distribution is very

FIG. 10.—A FOSSIL BLASTOID, A RELATION OF THE STONE-LILIES.

extensive, as they range through nearly every part of the Atlantic and Pacific, from 82° N. lat. down to Heard Island in the Southern Sea. They are largest and most varied in the tropics, particularly in the shallow water about the West Indies and Philippine Islands, and in the Malay Archipelago. It is especially in the two latter localities that they reach their highest degree of development, some forms having not far from two hundred arms. The large feather-star of the Arctic seas, although rivalling these giants in the spread of the arms, possesses only ten of these organs, and is therefore much simpler in its construction than they are. It must be said that we know very little about the fossil feather-stars in this respect, as the arms are so rarely preserved, but their bodies were larger on the whole than those of existing species.

Two distinct and interesting fossil forms with practically no stalk are allied to the Crinoids; they are the Cystids and the Blastoids (Figs. 9 and 10).

THE EVOLUTION OF THE RIFLE.

By A. HILLIARD ATTERIDGE.

"CARAN D'ACHE" in his humorous sketches of the "History of the Art of War" shows in two pictures the contrast between the early days of firearms and their present development. Of course, as is his wont, the artist exaggerates a little. In the first, two arquebusiers of the early fifteenth century face each other at close quarters, with their heavy hackbuts, or hand cannon, supported on forked rests, and are about to apply the smouldering match to the touch-hole. The range is not more than twenty yards, if it is as much. In the next picture we see a French rifleman of to-day in action. So extended is the firing line that his comrades to left and right do not appear in the picture, and the invisible enemy is far away on the skyline. The soldier has fired and rests, with his Lebel near him, thinking where he will try his next shot, and as puzzled for a reply as our soldiers often were in South Africa.

FIG. I.—ARQUEBUSIERS IN THE SEVENTEENTH CENTURY.
(From "Cruso's Militarie Instructions for Cavallrie, 1632.")

From the old matchlock hackbut or arquebus (Fig. 1) to the modern small-bore repeating rifle there has been a steady evolution through more than four centuries—very slow at first, wonderfully rapid in the last sixty years. Indeed, but for sporadic earlier efforts, it might be said that the evolution of the rifle was carried out in the nineteenth century, and chiefly in the second half of it. Our victories of the Peninsular War and crowning triumph of Waterloo were won by troops who were nearly all armed with a clumsy smooth-bore flintlock, differing in no essential particular from the weapons carried by the musketeers of Naseby and Marston Moor, and of the infantry that fought at Ramillies and Blenheim. The rifle came into general use as the result of our Crimean experiences. Our soldiers first used a converted breech-loading rifle under Napier in Abyssinia in 1868, and the small-bore repeater first came into action in British hands on the North-West Frontier of India in the 'nineties. We have here the three chief stages in the evolution of the rifle—the muzzle-loader, the breech-loader, and a small-bore repeater.

But the rifle, as well as the breech-loader, is older than the nineteenth century. It was a sixteenth-century invention, and we owe it to German armourers—long the most skilful in Europe. We find the first record of it in a decision of the Swiss Government as

to a question of fairplay and equal weapons in shooting matches, which was the result of disputes at some Swiss Bisley about the year 1563. The decree sets forth that inasmuch as in recent years "the art of cutting grooves in the chambers of guns with a view to making their shooting more accurate has been introduced, and the disadvantage resulting therefrom to the ordinary marksman has led to discord," such grooved guns are not to be used except in shooting for special prizes, when all are equally armed. In some of the early grooved muskets the grooves were parallel to the axis of the barrel. To August Kulter, an armourer of Nuremberg, is attributed the invention of a spiral groove, a true "rifling" of the barrel. He lived about the time of the Swiss decree, and perhaps his "grooved guns" were the cause of the "discord" among the mountaineer marksmen.

FIG. 2.—GUNS USED BY ARAB TRADERS AND SLAVE DEALERS.

Clerics have been often inventors of warlike weapons. It was a Bishop of Munster, in the seventeenth century, who first suggested the elongated bullet, but there is reason to believe that he tried it with smooth-bore guns. So fired, a long bullet soon begins to turn over and over in the direction of its length, loses its

direction, and comes to the ground at a very short range. It was in 1729 that a German inventor in Russia suggested that the elongated bullet should be fired from a rifled barrel, and that its base should be hollowed, so that the force of the explosion should drive the lead into the grooves, and so set the bullet spinning on its axis. His name—Lautmann—is worthy of record as perhaps the first who grasped the practical theory of the rifle. He published a little book on the subject, but could not get his own or any other Government to take up his ideas, and for more than a hundred years after he was dead and forgotten the smooth - bore musket was still the regulation weapon of all regular armies.

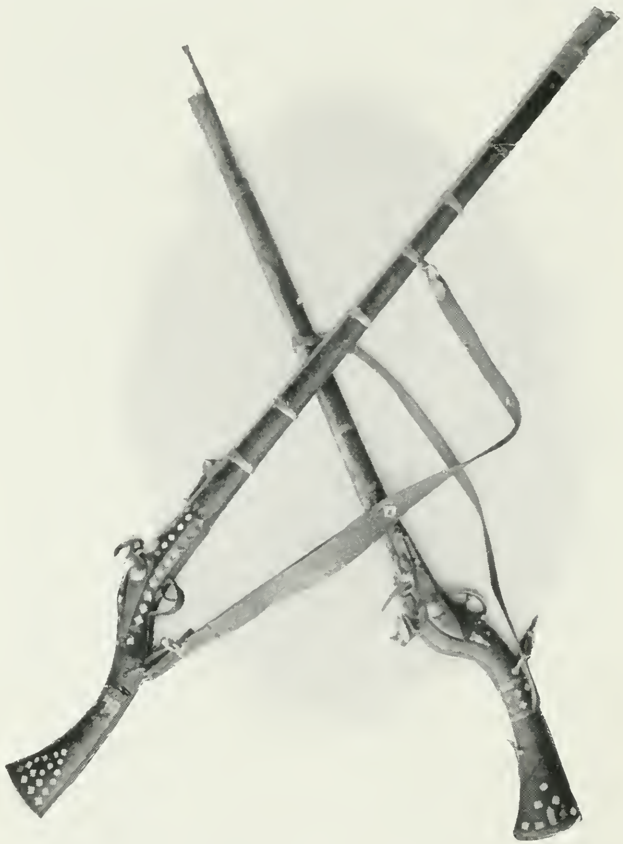


FIG. 3.—JEZAILS, USED BY AFGHAN HILLMEN.
(From the collection of Major-General L. H. E. Tucker, C.I.E.)

The real difficulty of making a good rifle without machine tools, and the supposed difficulty of providing it with an effective bullet that could be easily rammed down the long barrel (though Lautmann had shown the way), long prevented Governments from manufacturing rifles in any number. But in Germany the weapon was used for sport. The chamois hunters of the Alps, especially in the Tyrol (Fig. 4), began to provide themselves with rifles in the eighteenth century. In America the backwoodsmen began to use it in the chase and in frontier warfare with the Redskins. In the war of the American Revolution these rifle-armed marksmen, skirmishing in the woods, used to shoot down King George's redcoats at ranges at which the "Brown Bess" could not reply, and especially knew how to pick off the officers with deadly skill. Among the German mercenaries hired from the petty princes of the Fatherland for service in the British Army against the colonists, companies of *Jagers*, rifle-armed huntsmen, were in special request, and a few of our own soldiers were given rifles, and learned in the rude school of war light infantry or skirmishing tactics. In all these early rifles the bullet was spherical. It weighed an ounce or more, for the barrel had a large bore to facilitate the cutting of the grooves. It was made to take the rifle in two ways, both objectionable. Either the bullet was slightly larger than the bore, and was rammed down by main force, the lead being thus squeezed into the grooves, or it was just the diameter of the bore and

was wrapped in a greasy patch of thin cloth, which was forced into the rifling. To drive it down, the rifleman sometimes used a wooden mallet applied to the top of his ramrod. Rapid fire was out of the question, and loading was a laborious and sometimes a dangerous operation. The Tyrolese rifle, with its long barrel, was very heavy. To shoot at all well the pull of the trigger was made as light as possible. It was a hair trigger, that could be let off with a touch. The Tyrolese used to say that a gust of wind might let off a chamois hunter's rifle. Baker's rifle, used by the Rifle Brigade, was kept under nine pounds by making the barrel so short that it might almost be classed as a carbine. The gain of using a rifle with a spherical ball was only a very moderate one. It was partly the result of the ball fitting the bore more closely, so that the charge gave a greater initial velocity and a longer range; partly the result that as the ball spun on its axis any irregularity of form was compensated for by every part of it in turn encountering the pressure of the air as it spun, so that one irregularity compensated for the other; partly, too, the result of the steadiness of flight resulting from the spin, on the principle of the gyroscope, by which a rapidly revolving body has a tendency to keep its axis of revolution always in the same plane.

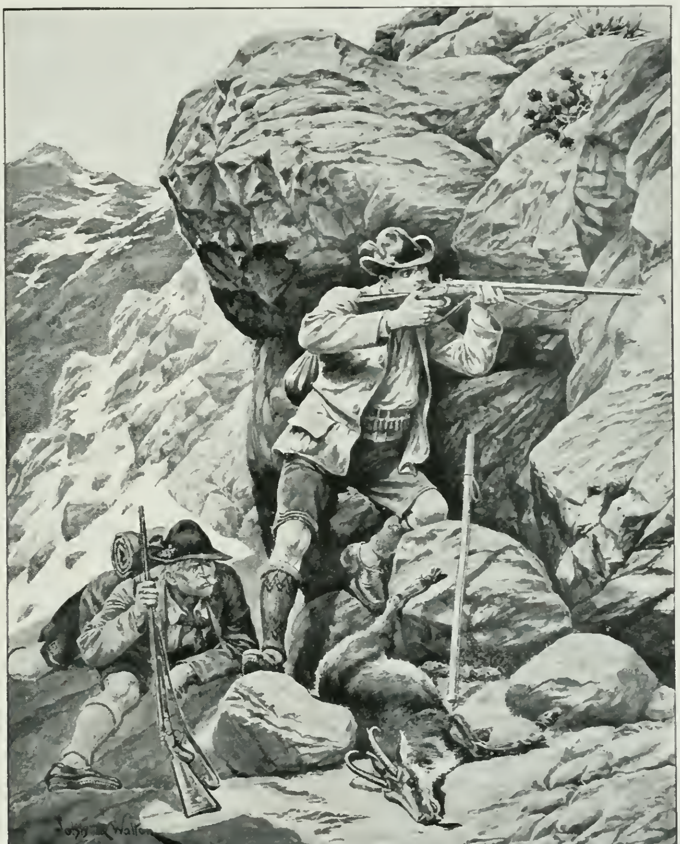
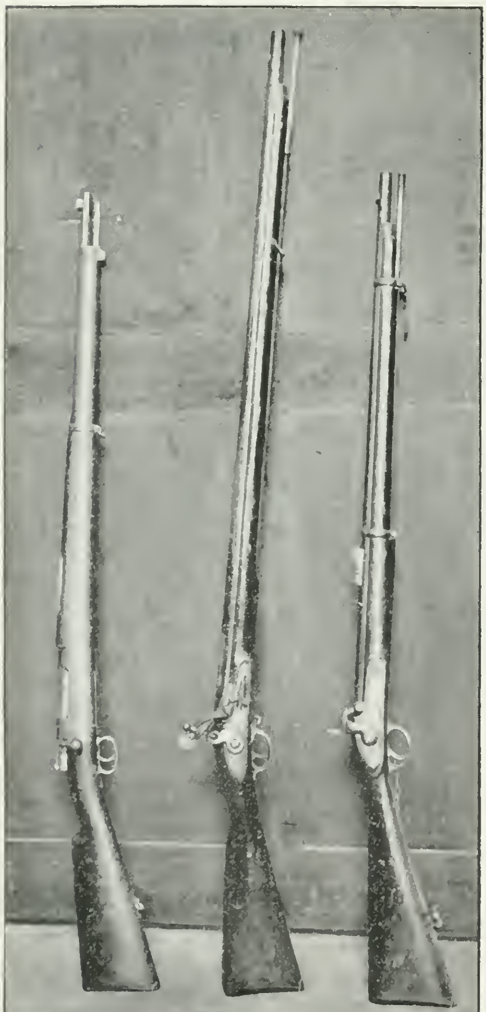


FIG. 4.—SHOOTING THE CHAMOIS IN THE TYROLESE ALPS.

It was in 1835 that the Brunswick

Rifle was adopted by the Rifle Brigade, and began to displace the old "Brown Bess" (Fig. 5, II.) as the weapon of our Army. It had a percussion lock, and old soldiers did not like the new-fangled invention. Percussion caps, they argued, were all very well for Frenchmen and Germans who fought near home, but it was a dangerous innovation for British soldiers who had to fight in all kinds of far-off lands. One could get flints anywhere, but could one depend on a constant supply of percussion caps? This coming of the percussion cap is a notable event, for it made the breech-loader a practical possibility. The Brunswick rifle, so called from the place of its invention, had another improvement. The spherical bullet had a ring of lead round it, and if this ring was placed at right angles to the axis of the barrel it could be rammed into the grooves, of which there were only two, with moderate effort. But our War Office minimised this small gain by keeping the old greasy patch of cloth used with Baker's rifle, so that the bullet wrapped up in it might easily be turned the wrong way. It was a chance whether the ring took the grooves or not.



I. II. III.

FIG. 5.—THREE FAMOUS GUNS.

I., Mauser; II., Brown Bess; III., Minié.

(Photographed at the Royal United Service Institution, Whitehall, S.W.)

Six years later the Prussian Government took a great step forward, and adopted a very poor kind of breech-loading rifle. This was in 1841. Twenty-five years later, on the battlefields of Bohemia, it became famous as the "needle gun," and all the armies of the civilised world adopted breech-loaders. But before we examine this change from muzzle- to breech-loading, we must follow a little farther the evolution of the older type of rifle.

There had been rifle regiments in France since 1837, when the Chasseurs (hunters) de Vincennes were organised by the Duke of Orleans, and the next great step forward was made by a Frenchman—Captain Minié—though the idea of his rifle had already been worked out by an Englishman, who could not get our Government to adopt it. By the way, it seems to be a settled policy of our Government to refuse British inventions until the foreigners have worked out and adopted something of the same kind. It was so with the Minié rifle (Fig. 5, III.). The new weapon was sighted to 1,000 yards. It had three grooves. The bullet was elongated, with a hollow base. In

the hollow of the base a small iron cup was fixed, and the effect of the explosion was to drive the cup into the bullet, expand its base, and so force the lead into the grooves. The rifle took its name from Captain Minié, its inventor. Fifteen years

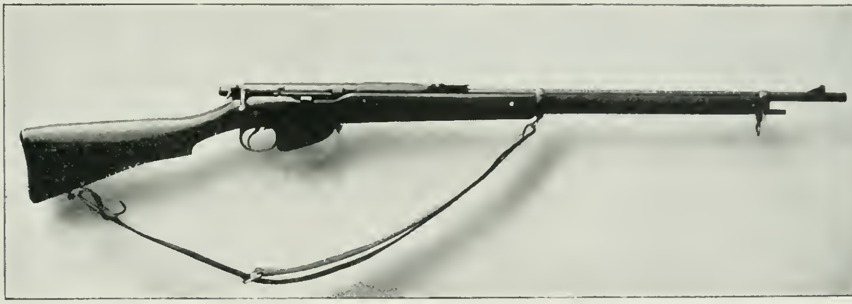


FIG. 6.—LEE-ENFIELD RIFLE: MARK II.

before, a rifle on the same principle had been invented by an English gunmaker—W. Greener—a hard wood plug taking the place of the iron cup. It had successfully passed a practical trial under Government supervision, and it had been shown that it could be loaded as easily as a smooth-bore, but the War Office rejected it on the ground that it had too complicated a bullet. Captain Minié received from the Imperial Government of France half a million of francs (£20,000) for the invention of his bullet. After the Crimean War, when the Minié rifle was used by our troops as well as the French, Parliament voted Greener a gratuity of £1,000 "for the first public suggestion of the principle of expansion, commonly called the Minié principle, in 1835."

The Minié rifle won its first triumph in the Crimea. Readers of Kinglake will remember his anecdote of the young staff officer who asked Lord Raglan if it was not time to open fire, as the French were already in action, and Raglan's answer, "Are they? I don't see any return fire." The Russian narratives of the Alma show that there was no return fire because, though the French rifles had opened with deadly effect, the range was so great that it was no use attempting to reply with the smooth-bore muskets carried by the Russians.

The English rifle, an improvement on the Minié, was the regulation rifle till 1867, when it was replaced by the Snider, which was an Enfield with a breech-loading action added to it, as a stop-gap while the War Office was deciding the question of what breech-loading system was to be definitely adopted. Before this period three or four different patterns of breech-loading carbines had been adopted experimentally by our cavalry. As has been already mentioned, the first European army to adopt a breech-loading rifle had been the Prussian, and this as early as 1841. The idea of the breech-loader was much older. There are in the Tower armoury breech-loading small arms of the seventeenth century, in which a steel chamber holding the charge is slipped into the base of the barrel. There were small breech-loading mediæval cannon on the same principle, the loading chamber being secured by a wedge and screw. The first Napoleon experimented with breech-loading rifles, but was not satisfied with the results. In fact, while flint and steel and priming were the only recognised means of firing the charge, to combine a breech-loading action with flintlock firing, without making the whole

affair hopelessly clumsy and unreliable, was no easy problem. The principle of percussion firing opened the way for the modern breech-loader. In the Prussian needle gun, adopted in 1841, the breech was closed and opened by a sliding bolt worked by a lever. As in all the earlier rifles the cartridge case was of oiled paper, and, as a paper case could give no support to the percussion cap, the fulminating material was placed in a capsule on the base of the bullet. It was fired by a long, sharp striker or needle, which on pressing the trigger was driven by the lock through the whole length of the cartridge into the capsule.

The needle gun played its part in the revolutionary warfare of 1848, and became famous in the campaigns of 1864 and 1866; but, like the French Chassepot (adopted in 1867), and all the earlier breech-loaders, the theory was that the greased paper of the cartridge case would be destroyed by the explosion. In practice, its *débris*, added to the products of powder combustion, rapidly fouled the barrel. At the same time, however good the workmanship was, the hot powder gases in some degree penetrated the joints of the breech action, and not only altered the surfaces, but also fouled the mechanism, so that its easy and accurate action could not be counted upon after even a few shots had been fired. In the Chassepot and some other earlier rifles an effort was made to keep the powder gases out of the breech action by a plug or ring of rubber forced into the breech as it closed, but heat and pressure soon deformed, and partly melted, the plug, and often made the rifle useless at a critical moment. A great step forward was taken when the copper or brass cartridge case was adopted. In this England led the way. The copper case or shell affords a solid base in which to fix the percussion cap, and this enables a short striker to be used. This is a great gain, for the long needle of the old Prussian rifle was easily broken or bent. But a still greater gain is that on the explosion of the charge the metal case expands and is driven into close contact with the sides and end of the barrel, thus effectually cutting off the hot gases from the breech action. England led the way in this great improvement, though our first metal-cased cartridge—the Boxer pattern—was very defective. To extract the expanded cartridge the action of opening the breech has always to be combined with a device for seizing the base of the cartridge and forcing it out of the barrel. In the Boxer pattern the case was a thin brass tube with an iron base attached to it, and sometimes the extraction simply tore off the base, leaving the brass tube in the barrel. In such a case—and it happened not infrequently in some of our earlier Soudan battles—the soldier found himself suddenly disarmed, for he could not insert another cartridge in the blocked-up barrel of his rifle. All cartridges are now solid drawn, stamped out of a sheet of metal, so that base and tube are formed of one piece of copper or brass without any joint.

The various types of breech-loaders fall into two great classes—block and bolt action rifles. In the former a metal block, which can rise and fall or be turned to the side, closes the breech. The type most familiar to Englishmen is the Martini action, in which the block is hinged so that on forcing down a lever below the lock the front of the block drops and clears the breech of the barrel. The cartridge is inserted and the lever raised, bringing up the block into its old position, and at the same time compressing the spring of a striker. On pressing the trigger the spring is released and the shot fired. A catch which engages the rim or base of the cartridge forces it out of the barrel as the lever is depressed

to open the breech to reload. It is the simplest breech-loading action ever made, and has only gone out of use because the breech block of the Martini action occupies the best position for the magazine loading device that is now a necessary part of all military rifles.

In the bolt action breech-loaders, of which the Lee action is the best known in England, the barrel is closed by a steel cylindrical bolt the length of which lies in the same line as the barrel. It slides backward and forward, and has a short lever handle on the right side by which it is worked. On drawing it back the extractor pulls out the case of the fired cartridge, and the spring of the striker, which works inside the bolt,

1 3 2

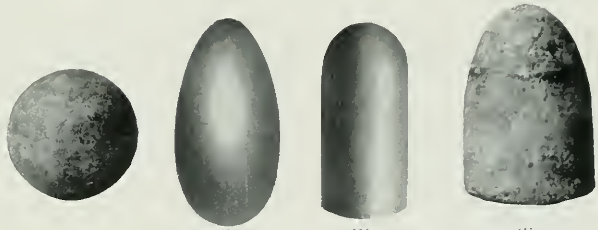
FIG. 8.—CARTRIDGES FOR MODERN RIFLES.

1, Lee-Enfield, Mark IV.; 2, Lee-Enfield, Mark II.; 3, Martini-Henry.

(From specimens at the Royal United Service Institution, Whitehall, S.W.)

is compressed. It is driven home by a movement which gives it a quarter turn and locks it in position, and the striker spring is then released by the trigger. Figs. 11–17 show the mechanism in detail.

As the breech-loader had been evolved from the old muzzle-loading rifle, so it in its turn led up to the repeating rifle. There had been attempts to make a re-



I. II. III. IV.

FIG. 7.—SHOWING DEVELOPMENT OF THE BULLET.

I., Brown Bess; II., Needle Gun; III., Chassepot; IV., Conical bullet.

(From specimens at the Royal United Service Institution, Whitehall, S.W.)

peating weapon even in the days of the muzzle-loader. Gossiping old Pepys tells of one he saw—"a gun to discharge seven times, the best of all devices that I ever saw, and very serviceable and not a bauble, for it is much approved of." In this gun it would seem that the seven charges were rammed down on top of each other, and fired in succession from the front. The man who handled such a weapon must have been a reckless fellow. Clearly, it was breech-loading that made the true repeater possible, for the revolver system belongs to pistols, not guns. The Swiss were the first to adopt a repeater as a national weapon. This was in the 'sixties, when most other European Governments were taking up the single breech-loader. The Swiss weapon—the Vetterli—had a supply of cartridges which were placed in a second barrel under the barrel proper, and fixed in the hollowed fore end of the stock. They were successively pushed backward, then raised to the level of the breech, and forced in as the breech-bolt was pushed home. This was also the type of the older Winchester, much used as a sporting weapon. It had, among other drawbacks, the disadvantage that when the magazine was full, the weight of the cartridges destroyed

the whole balance of the rifle, and led the soldier to aim low, and the balance of the rifle varied with every shot fired. In the Hotchkiss rifle the magazine was a tube in the butt, from which the cartridges, placed one behind the other, were forced forward to the loading point. A weak point of all tube-shaped magazines is that there is always some danger of the point of a bullet breaking the cap in the base of the next, with serious results, hence bullets for such rifles are always somewhat blunt-nosed. But it was with a tube magazine rifle—the Lebel—that France in 1885 again showed the way to the other great military powers, as she had done with the Minié in 1851.

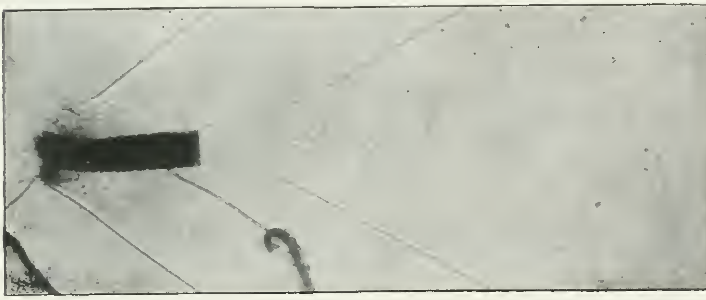
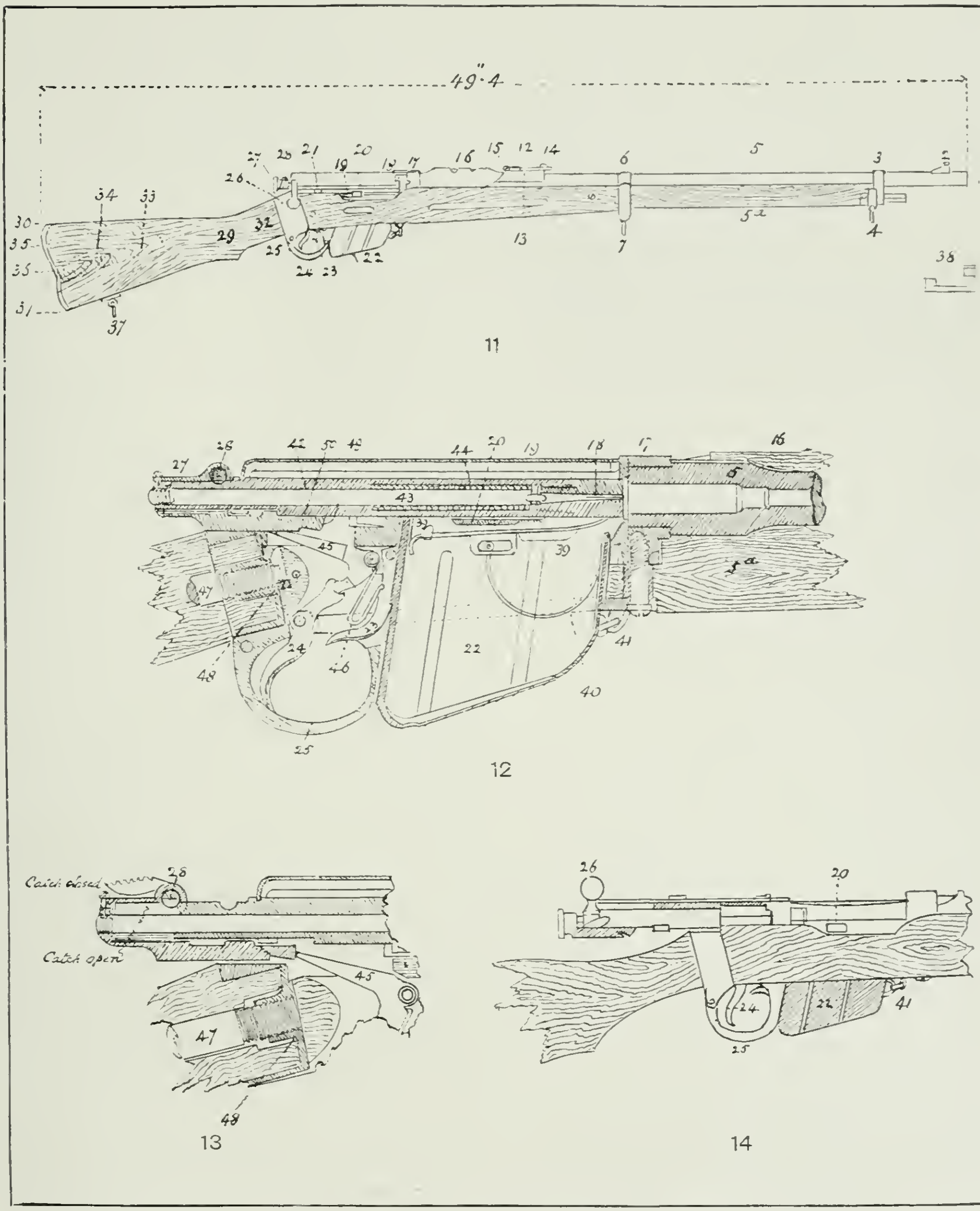


FIG. 9.—A BULLET IN FLIGHT, SHOWING AIR WAVES SET UP.
(From a photograph taken by Professor C. V. Boys, of the Royal Society.)

FIG. 10. RIFLE BULLET AFTER ITS PASSAGE THOUGH A SHEET OF GLASS, AND SHOWING FRAGMENTS OF GLASS FOLLOWING THE SHOT.
(From a photograph by Professor C. V. Boyes, of the Royal Society.)

The experts who worked out the Lebel for the French War Office, though they produced a weapon inferior in some respects in its mechanical details, grasped two important facts. First, that if the soldier had to fire more rapidly than had been possible with the old breech-loader, and used a smoke-producing powder, he would soon be surrounded by such a cloud of powder smoke that he could not see anything to fire at, and secondly that rapid firing would soon make his rifle too hot to hold. Now, some of the newer explosives are practically smokeless, and develop less heat than gunpowder. They selected one of these, which had the further advantage of causing less fouling in the barrel. Then, reflecting that if the soldier fired faster he must carry more cartridges, they made the calibre smaller, so that the bullet would be lighter. As the propelling force of the new explosive was greater than that of gunpowder, the hitting effect of the lighter bullet, only ·318 in. diameter, could be made equal or superior to that of the heavier old-fashioned ·450 bullets, for hitting effect means weight multiplied by velocity. Then, again, the higher velocity would give a better fighting weapon, for the path of the bullet on leaving the muzzle would be a flatter curve. With the older rifles one had



FIGS. 11–14.—THE LEE-ENFIELD MAGAZINE RIFLE AND ITS PARTS.

11, the rifle complete; 12, mechanism of breech; 13, section showing half-cock and safety catch; 14, section showing breech open.

1. Muzzle.
2. Foresight.
3. Nose cap.
4. Piling swivel.
5. Barrel.
5a. Fore end.
6. Lower band.
7. Lower band swivel.
8. Dial sight.
9. Dial sight plate.
10. Dial sight pointer.
11. Dial sight bead.
12. Back sight.
13. Back sight bed.
14. Back sight leaf.
15. Back sight slide.
16. Handguard.
17. Body.
18. Bolthead.
19. Cover.
20. Cut off.
21. Retaining spring.
22. Magazine.
23. Magazine catch.
24. Trigger.
25. Guard.
26. Bolt knob.
27. Cocking piece.
28. Safety catch.
29. Butt.
30. Heel of butt.
31. Toe.
32. Small.
33. Oil bottle.
34. Pull through.
35. Butt plate.
36. Butt plate trap
37. Butt swivel.
38. Sight protector.
39. Magazine platform.
40. Magazine spring.
41. Magazine spring link
42. Bolt.
43. Striker.
44. Mainspring.
45. Sear.
46. Sear spring.
47. Stockbolt.
48. Keeper plate.
49. Full bent. } Cocking
50. Half bent. } piece.

not to change the sighting once an enemy closed up to about 200 yards. One would hit him somewhere. At 200 he would be shot in the legs, at 100 he would be hit in the region of the waist-belt ; but if a shot sighted for 500 was fired when he was at 300 the bullet would whistle harmlessly over his head. With the new hard-driving explosive and the little bullet flying with a flattened trajectory, the range of "fixed sights," of almost point-blank firing, was extended from 200 to over 500 yards, and the zone of deadly danger was thus more than doubled, so that the frontal attack at close quarters seemed henceforth doomed to hopeless failure.

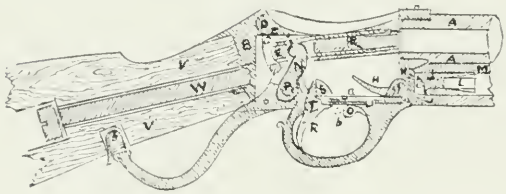


FIG. 15.—MARTINI-HENRY RIFLE AND ITS PARTS.

A. Barrel.	*N. Tumbler.*
B. Body.	*O. Lever.*
C. Block.	*P. Lever and tumbler axis pin.*
D. Block axis pin.	*Q. Trigger plate and guard.*
E. Striker.	*R. Trigger.*
F. Mainspring.	*S. Tumbler rest.*
G. Stop nut.	*T. Trigger and rest axis pin.*
H. Extractor.	*U. Trigger and rest pin.*
I. Extractor axis pin.	*V. Stock butt.*
J. Rod and fore end holder.	*W. Stock bolt washer.*
K. Rod and fore end holder screw.	*Z. Lever catch bolt spring and spring.*
L. Ramrod.	*a. Locking bolt.*
M. Stock fore end.	*b. Thumb piece.*

This was why the Lebel repeater was given its small bore and its smokeless cartridge. It was the cartridge rather than the mechanism that made it so formidable. German experts were busy on the same problem. The secret of their activity was well kept, and, working on similar lines, they produced the Mauser (Fig. 5, I), with as good a cartridge, though at first with the same defective repeating arrangement of an under-barrel tube magazine. This was improved upon later. Clearly, if a reserve of cartridges is to be loaded into the mechanism of the rifle, the best place for it is close to the loading point, and between the shoulder and the place where the left hand grasps the weapon, in fact near the centre of balance of the whole. Lee in America and Mannlicher in Austria adopted the device of a small case to hold a few cartridges, just below and behind the rear end of the barrel. In the Lee device the cartridges are forced up one by one by a zigzag-shaped spring. In the Mannlicher they are pulled up by an attachment to the breech action. But in the Mannlicher device, which was later on added to the Mauser rifle, there is the further gain that instead of the cartridges being loaded into the magazine one by one, they are served out fastened together in sets of five in a thin metal clip and dropped into the magazine five at a time. In our British Lee-Metford rifle the loading of the magazine is at best a relatively slow process. It is closed with a hinged slip of metal, the "cut off," and the rifle becomes a single loader, till the moment comes for "magazine fire" and the cut-off is pulled out, and the small reserve of cartridges rapidly expended. To reload the magazine is a more complicated business than loading a revolver. Our African experiences have taught us the advantage of a clip-loading magazine rifle, and such will be our improved Lee-Enfield, now undergoing experimental trials.

But another great change is already coming. More than one Government is considering the possibility of arming its troops with an automatic repeater, a rifle which, like the Maxim gun, will continue firing, extracting the empty cartridge, pushing in a live one, and firing again as long as there is a cartridge in the magazine and the soldier keeps his finger on the trigger. Such a weapon has been made in more than one form, and no one can say how soon it will be made so practical and effective that all

existing military rifles will have to be sent to the "scrap heap."

We have traced in bold outline the evolution of the rifle, through its various stages of muzzle-loader, breech-loader, and repeater, noting broad principles rather than details. Something has been said also of the evolution of the bullet (Fig. 7) and cartridge (Fig. 8), but there is no space to discuss the vexed questions of stopping power of the small-bore bullet, and the various forms of the rifling of the barrel. It must, however, be noted that it was soon found that the little bullet would not always stop the rush of a Ghazi on the North-West Frontier or a dervish in the Soudan. It had been found necessary to coat the little leaden bullet with a harder metal casing to prevent the lead stripping on to the inner surface of the barrel under the heat and friction resulting from its increased velocity in the bore. In Indian warfare methods were devised for making the casing of the bullet collapse on impact, so that the lead would "mushroom" and cause a disabling wound. Hence the Dumdum bullet. At the Hague Convention some of the foreign delegates protested that this was practically an explosive bullet, though, as a matter of fact, the effect was much the same as that of the big mass of soft lead shot from Snider or Martini. The use of the new bullet, or rather of its improved variety, the Mark IV., was abandoned by our army at the outset of the South African War, not so much in deference to those scruples as because it was found that the bullet with the weakened envelope had a dangerous tendency to break up in the barrel. The question of the bullet remains a puzzling problem. There are those who think that the solid-cased small-bore bullet will not stop a determined cavalry charge, and that with the small-bore repeater the day of lance and sabre and the rush of victorious squadrons has come again. Of course, these are for the most part cavalry officers, but there are infantry officers, too, who think that they may be right.

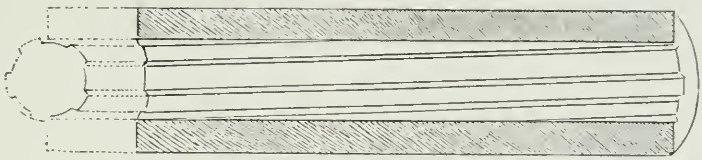


FIG. 16.—LONGITUDINAL SECTION OF LEE-ENFIELD BARREL, SHOWING "RIFLING"—1 TURN IN 10 INCHES.

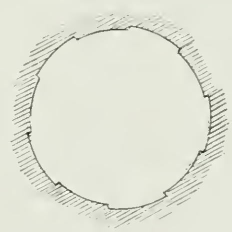


FIG. 17.—TRANSVERSE SECTION OF BARREL OF LEE-ENFIELD. ENLARGED, SHOWING GROOVES.

GOLD AND QUARTZ.

FROM time immemorial gold has been the object of man's keenest desires, and although the scientist has discovered other metals to which it has to give pride of place in point of value, the search for it is still prosecuted with unabated vigour. As an article of personal adornment and a standard of exchange, it has played and is playing a great part, but of late years the arts and sciences have claimed its services in increasing quantities, and the noble metal no longer depends for its value upon its purely decorative qualities.

FIG. I.—PROSPECTING FOR GOLD.

Inexperienced people have often mistaken a variety of minerals for gold—bright yellow mica or pyrites* generally—but a very limited knowledge of its properties would have saved them from the possibility of error. The great weight of gold alone separates it sufficiently from all substances at all resembling it in colour. Thus it is more than nineteen times as heavy as an equal bulk of water; or, in scientific language, its *specific density is* 19·6. It is, moreover, the most *malleable* of metals: it can be beaten out into sheets so thin that over a quarter of a million of them go to make an inch in thickness. Its ductility is not less remarkable, for a grain of gold may be drawn out into a wire 500 feet long.

All these qualities, added to the difficulty of finding it, have combined to place gold at the head of the aristocracy of metals. Since the days when Pactolus rolled over its golden sands, men have sought for it, fought for it, and died for it. No product of the earth has been so long studied and speculated on. Nevertheless, none has been so little known, or so thoroughly misunderstood as to its circumstances of deposition and mode of origin.

One popular idea, at least, concerning it, has been proved to be a fallacy, viz. its supposed rarity. The truth is that

* Chemically, sulphide of iron—the same substance which is known as "diamonds" in roofing slates, and as "thunderbolt" in the chalk.

GOLD AND QUARTZ.

1, NATIVE GOLD IN VEINED QUARTZ; 2 NATIVE GOLD IN FERRUGINOUS VEINED QUARTZ; 3, IN QUARTZ, WITHOUT VEINING; 4, TELLURIDE OF GOLD AND SILVER IN QUARTZ; 5, NUGGET OF GOLD; 6, NATIVE GOLD, ACCOMPANIED BY DECOMPOSED IRON PYRITES, IN QUARTZ; 7, 8, 9, 10, 11, 12, OTHER FORMS OF GOLD DEPOSIT.

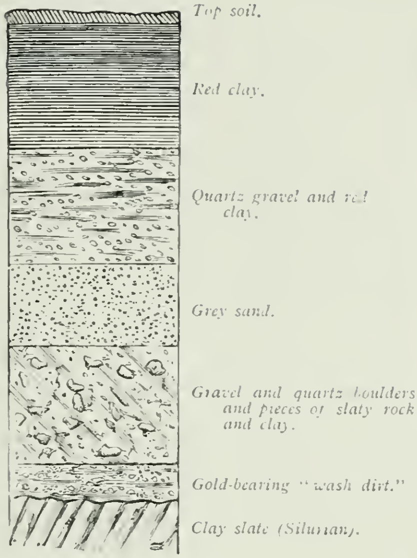


FIG. 2.—VERTICAL SECTION OF AURIFEROUS "DRIFTS" AT DUNOLLY, VICTORIA.

FIG. 5.—QUARTZ REEF AT FRYER'S CREEK, VICTORIA.

gold is one of the most generally distributed of all the elements. It may be found in all sorts of geological strata, and it is confined to no country. Even the sea water contains appreciable quantities, and the rocks of our island home have their store of the precious metal. Indeed, of late years gold mines in the neighbourhood of Dolgelly have proved highly remunerative. Probably there are other "veins" which would pay well for the working, for the Romans, although they worked gold mines in Britain, did not remove all there was of the precious element.

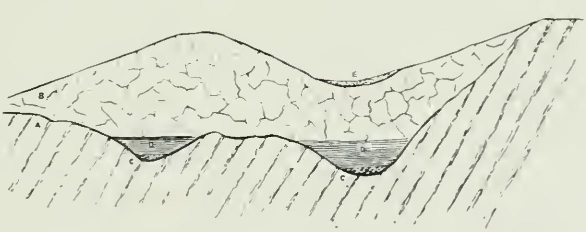


FIG. 3.—DIAGRAM OF STRATA IN A DIGGER'S "CLAIM."
A, false bottom (Silurian); B, false bottom (basalt); C, rich "wash dirt"; D, older drift; E, new drift, with stream.

Referring once again to the *distribution* of gold in the crust of the earth, we soon find that a deposit of gold may be of almost any age, from the geologist's point of view, and with this rather bald general statement we must dismiss a phase of the subject concerning which volumes have been written.

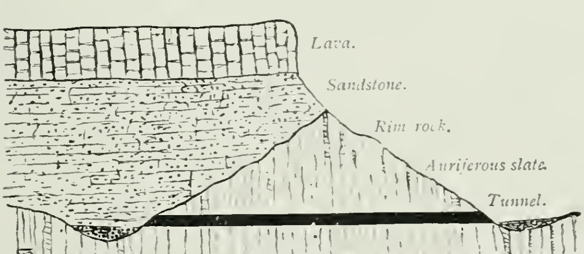


FIG. 4.—MAINE BOYS' TUNNEL, ILLUSTRATING THE OLD LAVA-COVERED GOLD DRIFTS OF CALIFORNIA.

Now we come to the question of *matrix*—that is, the substance which acts as the cradle for the gold. Quartz, an impure rock crystal, is the most common of all the matrixes known (*see* Coloured Plate). Veins of gold not bedded in quartz may be found in the neighbouring rocks, but the quartz, as a rule, is not far away.

These gold veins differ in some

essential particulars from ordinary veins, such as those containing, copper, lead, or tin. They form courses of quartz varying from a few inches to a hundred feet or more in width, running through the beds of rock like great dykes, and often, owing to the great hardness of the quartz, standing out like walls many feet above the surface of the country. Hence the appropriate name "reef" applied to them.

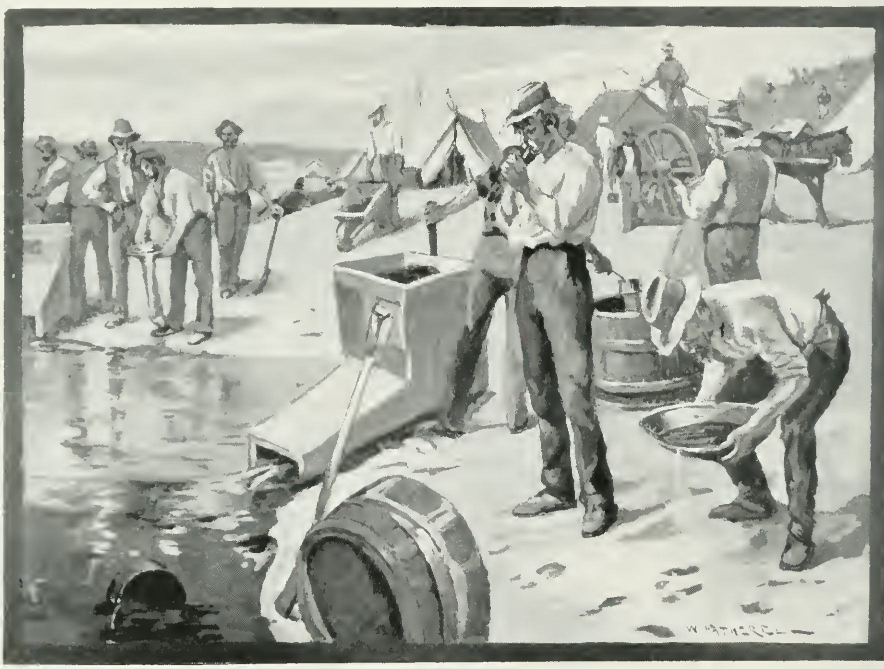


FIG. 6.—"CRADLING" AND "PANNING."

At other times reefs are irregular, shapeless, quartz-filled spaces, without apparent order, and very unlike lodes of baser metals. In Fig. 5 we have a section showing a Victorian gold vein of this character. It will be seen that no dislocation of the encasing bedded rocks necessarily attends the presence of reefs. It will also be noticed that from surface appearances little or nothing could, in cases of this kind, be predicted as to the probable width, direction, or continuation of the vein below ground. Still, by dint of practice, gold prospectors have come to know—or to think they know—when the quartz looks "kindly"—that is, whether it is likely to hold gold or not. If the "kindly" look be justified, gold *may* possibly be seen at the outcrop of the reef, but more usually it will have to be separated, by hard and tedious mechanical labour, from the quartz in which it lies concealed in specks too small for the eye to distinguish. In either case the surface appearances are apt to be deceptive, for auriferous quartz contains many other substances besides gold—and those, too, in a chemical form that renders them peculiarly liable to decomposition by atmospheric agencies. Now, the quartz being to some extent held together, as it were, by these substances, becomes, when they are decomposed, itself crumbled down, and the heavier unaltered and almost unalterable gold remains at the surface, *minus* much of the matter which originally accompanied it. It follows,

Photo: Messrs Wadds Brothers, Van[illegible]r, B.C. Supplied by the Ymir Gold Mines Co., Ltd.

FIG. 7.—WINTER IN THE FAR NORTH-WEST.

The view represents the dam at the Ymir Gold Mines before the leakage was made good.

therefore, that a reef is often richest at the surface—not, as has for years been very generally believed, because the gold occurs in greater quantity in the upper portions of the reefs, but by the mere effect of wearing away.

Although, as has been already mentioned, the gold is not often visible to the naked eye in the quartz, it occasionally happens that lumps of considerable size are found embedded in the white or reddish quartz rocks. Thus, the largest nugget on record was found in 1858 at Bakery Hill, Ballarat; it weighed 2,217 oz. 16 dwt., and brought £10,500 to its lucky finders, who, not inappropriately, named it the "Welcome Nugget."

We have no means of ascertaining the exact geological date of the in-filling of the reefs, but there is much good reason for believing that it took place chiefly at the close of the "Palæozoic" times. From that period to the latest within the scope of geology the history of these veins is a blank. We know nothing of them until we see them in "Post-Tertiary," or, as some say, "Quaternary," times, cropping across the exposed edges of the uptilted and altered rocks, much in the same position as we find them now. Then, as now, the decomposition along their exposed edges was carried on chemically by air and rain, the eroded quartz—"mice-eaten," as the miners call it—was detached and crumbled, leaving the heavier gold behind it, and then, as now, or perhaps more than now, the constant waste of the land, called "denudation," slowly but surely carried on its work of destruction and change, transporting quartz and gold, as gravel and nugget, to the neighbouring slopes and gullies, and as sand and clay and dust to the more distant river-valleys. The quartz-miner imitates Nature in a rude way by crushing the quartz in stamp-mills (Fig. 8), and then collecting the gold from the crushed mass by various chemical expedients.

It is in these gravels, sands, and clays—collectively known as "drift" (Figs. 2, 3, and 4)—that much of the gold of the world has been found. In these drifts the gold-digger of early Australian and Californian times worked. They are still the poor man's diggings, requiring little capital to wash out the gold, while the quartz-reefs demand a considerable outlay. In California they are known as "placers."

The gold drifts are relatively of different ages. Thus, they consist not only of deposits due to existing streams, but often represent the *débris* brought down by rivers long since dried up and lost. In Australia this has more than once been illustrated in this manner. A lonely digger, whom, in his own slang, we will call a "hatter," opens out a solitary "claim" in the valley of an existing water-course, and sets to work digging and washing. The gold-bearing loam, or "wash-dirt"—the "pay-dirt" of the Californian—is poor, and after a time the "bottom" or hard rock is reached. The miner's hope rests on getting to the "bottom" or "bed rock." Here the heavy gold worked down by the stream will have settled. If it is to be found anywhere, it will be here. If the "bed rock" has stopped no riches in their course, then all further search is useless, and the disappointed "hatter" strikes his camp, and departs to other fields. Soon after comes the digger's gleaner—the humble "fossicker." He is content with smaller earnings than his predecessor, and works the deserted "claim" in his turn. By luck or instinct, or perhaps even by experience, he fancies the hard rock may be but a "false bottom," and by dint of patient toil sinks through it. Fortune (in this imaginary case) favours the brave, and, sure enough, below the bottom rock, clays, sands, and gravels occur once more—with possibly a rich auriferous wash-dirt and "cement,"

or conglomerate, at the base, resting, this time, on the denuded Palæozoic beds—the true "bottom." Here let us leave our "fossicker" rejoicing in a "lob" of gold such as in real life "fossickers" seldom find, in "spangle," "paint," "flour," "heavy," "shotty" gold, and "nuggets"—and see how geology explains the matter.

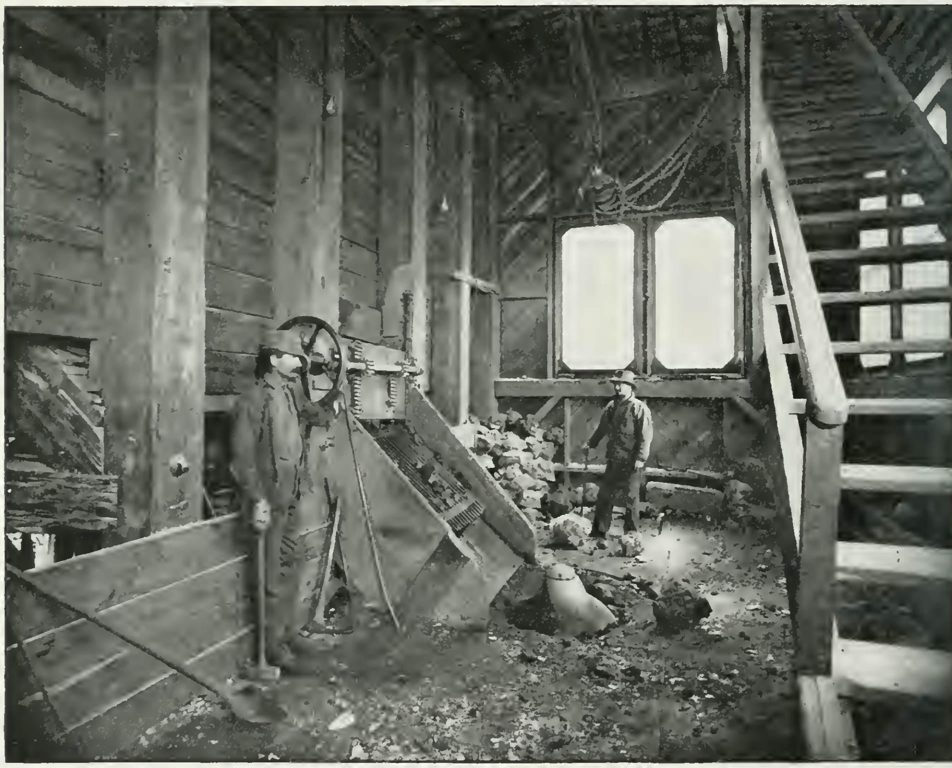


FIG. 8.—IN THE CRUSHER HOUSE.

(By permission of the Ymir Gold Mines Co., Ltd.).

In the valley, *c* (Fig. 3), there accumulated in long past times the auriferous drift from the hills. Then came the overflow of a volcanic eruption, filling the valley with lava—now basalt. Such eruptions were frequent in Australia up to almost within the historic period. Next followed the inevitable "denudation" or wearing away of the cooled and hardened lava, the bottom rock of the unsuccessful "hatter," and the establishment of the existing stream with its valley and gold-bearing deposits — necessarily poorer, however (time of formation and reduced area considered) than the older and lower "wash-dirt." Though our "hatter" and "fossicker" be persons of no particular consequence, they have served to illustrate facts of common occurrence in Australia and North-West America (Fig. 7). The great gold "leads" of Ballarat are, many of them, merely old river-beds underlying, and, so to speak, "bottled up" by, great sheets of basaltic lava; and the same thing happens in the Far West.

In some rare instances true gold lodes are found unassociated with quartz. They thus occur in Transylvania, at the Vöröspatak mines, where veins of carbonate of lime are worked of which the sides or "cheeks" consist of symmetrical layers

Photo: Caney.

FIG. 9.—WASHING FOR ALLUVIAL GOLD.

Gold is roughly seven times as heavy as the material in which it is embedded. Separation is therefore easily effected by the action of running water. A good water supply is consequently of the utmost importance.

of gold varying from one-half to one millimetre in thickness. In this exceptional case, the containing or "country" rock is of igneous origin—an old quartzose lava known as Dacite—and the gold is often beautifully crystallised in perfect cubes and octahedra.

But besides occurring in detached and more or less rolled fragments in drift, or encased in the quartz of reefs, or less frequently in other forms of veins, gold is found disseminated widely, though thinly, throughout the rock formations of the world. In this condition, however, so minute are usually the proportions in which it has hitherto been detected, that its presence can only be made manifest by means of delicate chemical tests. The ancient quartzites of Scotland, the basaltic dykes of Britain, the Carboniferous Limestone of Bristol, the Coal Measures of New South Wales, the Triassic and Jurassic rocks of the Continent—all these have yielded gold to the analyst.

Such are the leading facts. How are they explained? Whence this all but universal presence of gold? Whence its concentration in certain veins? And whence its wide dissemination in rocks of all ages? Conclusive answers to these questions there are none, probable answers there are a few, but of possible and impossible the number is, as might be expected, great.

Were the fissures or veins filled by the condensation of heated fumes from below, from the interior of the earth, or by depositions from mineral waters similarly heated? Or were they filled entirely from above, from the tricklings and evaporations of our surface waters? Are the veins the result of all these agencies combined? These are but a few of the oft-discussed but still doubtful points as to lodes. But they scarcely touch the subject of dissemination in sedimentary rocks. Here there are but two probabilities. Either the gold is due to the erosion of pre-existing veins—and this is undoubtedly true for *some* of it—or it is due to the *sea*.

This last alternative is perhaps startling, but when we add that all sea-water contains *some* gold, and when we reflect on the timeless age of the ocean, on its presence in former times wherever bedded rock is found, it will be readily admitted that here, at last, we may have a clue to the origin of much of the gold as we now find it. But Nature loves to work in various ways, and if we must, according to the present state of our knowledge, look to the sea as the great golden treasury of the globe, we must yet remember that co-operation from some of the other sources enumerated above may also have been brought into play.

THE CONQUEST OF THE AIR.—II.

BY THE REV. J. M. BACON.

AFTER the termination of Mr. Glaisher's labours, the scientific side of aëronautics in England became sadly neglected, and, important as had been the results obtained, anything like due interest in them, so far as those in authority were concerned, seems to have entirely languished, so much so that up to the present hour no more public money has been forthcoming for scientific ballooning properly so called. It has, however, been otherwise in other countries, and it is now necessary to glance, however briefly, at what has been going forward in the land whence the balloon had its birth, as also on the further side of the Atlantic.

As long ago as the year 1850 two Frenchmen, MM. Baral and Bixio, conducted two lofty ascents, for the express purpose of investigating the laws and constitution of the atmosphere, and though the practical results obtained were comparatively small, their names as painstaking and intrepid scientific aëronauts cannot be omitted in this record.

Some seventeen years later M. C. Flammarion undertook a series of ballooning voyages ostensibly for physical research, and these were further followed up by MM. de Fonvielle and Tissandier, who were for many years partners in the perils and rewards of aërial travel.

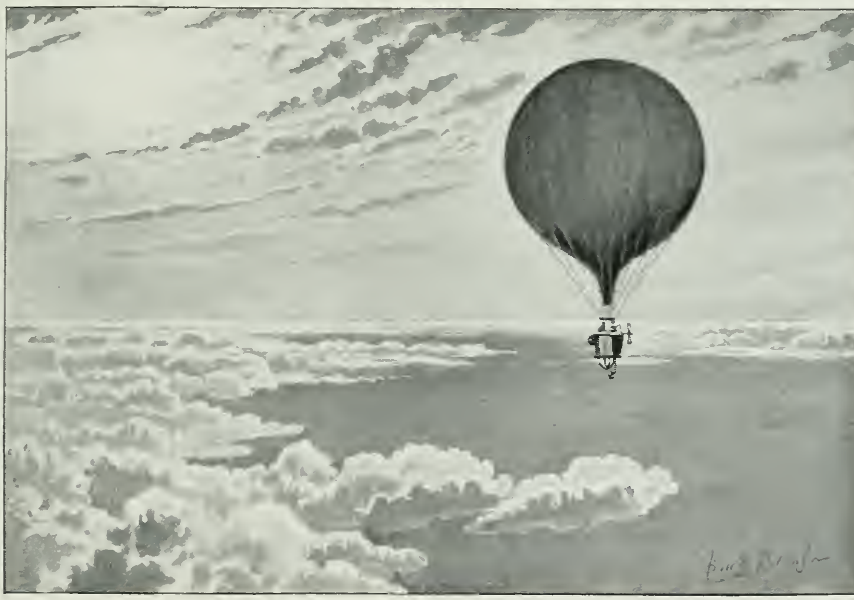


FIG. I.—ABOVE THE CLOUDS.

It is here necessary, for the sake of as far as possible preserving chronological sequence of events, to leave for the present the scientific balloon, and follow the fortunes of the balloon as used in warfare. It would appear that as far back as the year 1794 a balloon had been turned to account in military operations. This was

at the battle of Fleurus, when one, Guyton Morveaux, making an ascent, succeeded in giving important information to Jourdan, who was commanding the Revolutionary army. At the battle of Solferino, June 24th, 1859, a reconnoitring balloon on the side of the allies and in charge of two Frenchmen, the brothers Godard, was considered to have rendered valuable service; and when, three years later, the American War broke out, the Federal Army for a considerable period made systematic and successful use of a captive balloon for purposes of reconnaissance. The capacity which was found of best service was 26,000 cubic feet, inflated with hydrogen. This gas was manufactured as required in the field, the equipment needed being merely a squad of some thirty men under an officer, also four horses to convey the two generators used, and another four horses to drag the carts which carried the acid and the balloon itself. The requisite drill appears to have been a simple matter, and the whole method would seem to compare very favourably with that adopted by our troops in the recent campaign in South Africa.

At the beginning of the next decade (1870) balloons were turned to most remarkable use during the siege of Paris. More than seventy, which were in all cases free balloons, were manufactured within the city, and, being chiefly manned by sailors, were dismissed at frequent intervals during a period of four months for the purpose of carrying despatches beyond the enemy's lines. The manufacture was carried on at the disused railway stations, a varnished calico sufficing for the material, which was made up into globes containing about 70,000 cubic feet of ordinary gas. It is calculated that some two millions and a half of letters, and no less than two hundred passengers, were conveyed out of the besieged city. Among those who escaped was M. Gambetta, who arrived in safety at Rouen. About twenty passengers in all were either killed or taken prisoners, and a few others more or less injured.

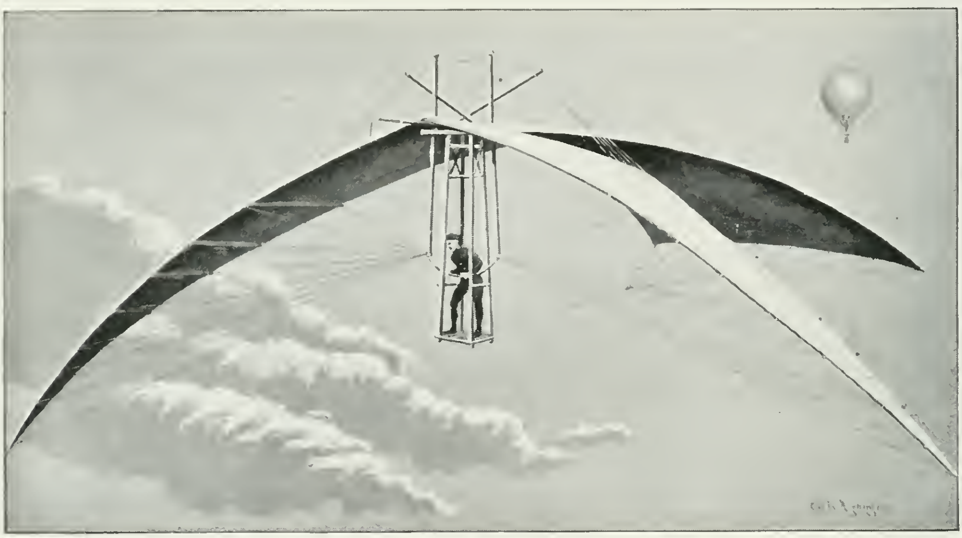


FIG. 2.—DE GROOF'S FLYING MACHINE.
The luckless inventor of this contrivance met with his death through a hitch in the machinery.

A balloon of colossal proportions, appropriately named "The Giant," and possessing

a capacity of 215,000 cubic feet, was constructed by M. Nadar soon after this, and though most elaborately fitted and equipped it may be almost unnecessary to say that this overgrown monster served only to show the folly of building balloons of undue size. Its vast envelope, on reaching the earth in descent, passed out of all control when any considerable wind was blowing. At the conclusion of its trial trip the car dragged for nearly a mile, sadly bruising its occupants. A fortnight later worse disaster ensued, the passengers sustaining many serious injuries, while the balloon burst.

Jules Duruof, accompanied by his wife, in attempting to cross the North Sea from Calais by night, was rescued from the water only with great difficulty, and after terrible sufferings, by an English vessel. The horror of this event was eclipsed, however, by a real tragedy which came into the experience of M. Tissandier in the year 1875. The misadventure resulted from an attempt to reach an extreme altitude, the voyagers, besides M. Tissandier, being MM. Crocé-Spinelli and Sivel. At a height of only 23,000 feet the party were feeling distressed and enfeebled; nevertheless, ballast was cast out, and the ascent continued. Ere 25,000 feet had been reached, Tissandier became stupefied, and, on recovering consciousness, found the balloon descending and both companions in a fainting condition. Throwing away more ballast, Tissandier again became unconscious as the balloon rose once more to a vast height, and, on finally coming to himself, the veteran aëronaut found both his companions lifeless, and himself scarcely able to control his fast sinking balloon.

FIG. 3.—MELLIN'S AIR SHIP.

A few months previously the originator of an aërostat partaking rather of the nature of a flying machine met his death. This was Vincent de Groof, whose apparatus is shown in Fig. 2. This unfortunate gentleman seems to have lost his balance in trying to detach his machine, which, falling from a great height and failing to open, was, together with its inventor, dashed to pieces.

It was about this same period that experiments began to be made in the direction of a navigable airship, and not without success. The famous engineer M. Giffard was one of the first to devote his unrivalled skill to the solution of the problem. Building an elongated balloon upwards of 100 feet in length, he endeavoured to control it by a rudder and screw driven by a steam engine of extraordinary lightness. Blindness, unhappily, prevented the proper development of his invention.

Another French engineer, M. Dupuy de Lôme, endeavoured, though unsuccessfully,

to substitute manual for steam power. Some ten years later the brothers Tissandier took up the work, and with the improved mechanical aid then available made some considerable strides towards success. In place of steam, they used an electric motor driven by bichromate cells.

FIG. 4.—IN MR. SPENCER'S WORKSHOP.

By far the most important trials were now made by the French Government, under the direction of Captains Renard and Krebs, who. also adopting electrical power and a cigar-shaped balloon of 165 feet in length, succeeded more than once in driving their vessel against a light wind and returning to their starting-point. This was in the year 1884.

By this time other methods were occupying the attention of mechanicians. A rival school to that of the inventors of navigable balloons had arisen in those who argued that the right principle for a flying machine would be found in some form of apparatus which, being not lighter but heavier than air, would offer smaller opposing surface to the wind, and be capable of being operated by motors of superior power. Foremost among the advocates of this principle must be mentioned two famous Americans, Professor Langley and Sir Hiram Maxim. Their position is well given in Sir Hiram's own words: "In all nature we do not find a single balloon. All nature's flying machines are heavier

than the air, and depend altogether upon the development of their dynamic energy." Professor Langley devoted his talents to working models; Sir Hiram Maxim, on the contrary, to an actual machine of vast proportions. The professor, adopting the idea of the well-known flying toy invented by Penaud, and operated by india-rubber cords, made an elaborate series of experiments over the Potomac River with models which weighed only a few pounds, and were worked by a miniature engine. In his earlier attempts he ultimately succeeded in making his model perform true flight for one or two minutes at a speed exceeding twenty miles an hour.

The machine which Sir Hiram Maxim designed weighed no less than 7,500 lb., with a spread of over 100 feet; the screw propellers, each of two blades, were eighteen feet in diameter, and the engines could be worked up to 360 h.p. The machine, for starting purposes, was made to travel on two railway lines, and various preliminary trials of a highly encouraging nature were embarked upon. These, however, terminated by the giving way of an axle-tree, and the consequent disablement of the apparatus. The great experiment proved satisfactorily that a practicable flying machine could be constructed which, driven by steam only, would have a lifting effect greater than the weight of the machine.

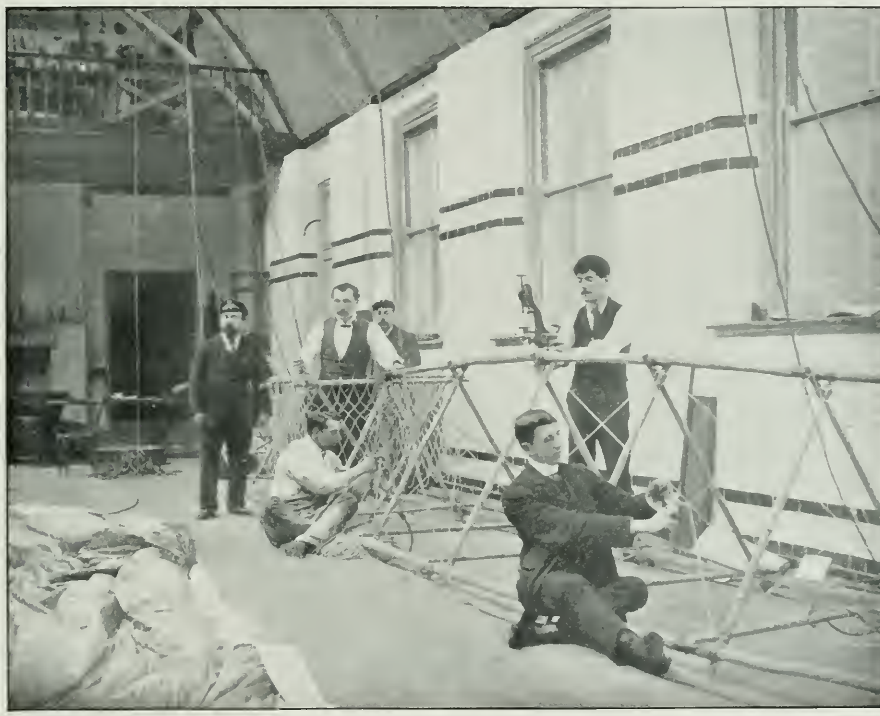


FIG. 5.—IN MR. SPENCER'S WORKSHOP: FITTING UP THE FRAMEWORK OF THE CAR.

Before following up the further developments of aerial machines consequent on the introduction of improved petrol-driven and other motors, it will be well to glance at another mode of traversing the air which was prosecuted at this period with success not unqualified with disaster. This was the practical feat known as "gliding," referred to in my first paper.*

* CASSELL'S POPULAR SCIENCE. Vol. II., p. 261.

Lilianthal, of Berlin, was the first to reintroduce in modern times this mode of flight with any measure of success. Imitating the soaring motion of birds as far as he was able, Lilianthal constructed outspread wings, and launching himself from gradually increased eminences, was eventually able to traverse several hundred feet before reaching level ground. In the end, in 1898, he lost his life by being precipitated with his machine from a considerable height.

Two years later a valuable young life, that of Mr. Percy S. Pilcher, was sacrificed in a very similar manner. Mr. Pilcher, who had received his early training in the Navy, and was also an engineer, took up the experiments of Lilianthal with an improved machine, and when towed at speed by suitable power, was able to rise off level ground. It was at an exhibition at Stamford Park that his apparatus, becoming damaged by a shower of rain, gave way when in the air, and the operator, falling backwards, sustained injuries to which he shortly succumbed. Experiments in "gliding" have since been prosecuted with considerable success under Mr. O. Chanute, of Chicago, and others.

As closely akin to gliding machines must, of course, be mentioned the parachute, and this having practically dropped into disuse after the fate of Cocking, was at length revived once more with eminent success, and, moreover, without the slightest mishap, by the American aëronaut Baldwin, who gave a series of sensational exhibitions in England at the end of the 'eighties. Messrs. Spencer Brothers and others have since constantly practised parachute descents, and modern parachuting has come to be recognised as one of the safest, and certainly the most graceful, modes of descending from great heights in the air. Baldwin's parachute was said to measure only eighteen feet

FIG. 6.—PACKING UP READY FOR TRANSPORT.

in diameter, but parachutes are commonly made larger, without any aperture at the top, and in shape closely resembling an expanded umbrella.

Before the end of the year 1898 the name of M. Santos Dumont was known to the world as that of an ardent experimental aëronaut, for whom a successful future was predicted. This young Brazilian, aided by large means, by considerable mechanical skill, and, above all, by superb courage, commenced a series of experiments with navigable balloons driven by the modern petrol motor. His first airship was cylindrical, with rounded ends, measured 85 feet in length, and contained 16,500 cubic feet of gas. Ascending with this over Paris, the inventor, favoured by calm atmosphere, succeeded in performing very creditable evolutions in mid-air, till an accident to the engine brought the machine to the ground.

But this attempt of the bold Brazilian did not stand alone. Airships were truly in the air, and one was already being constructed by Professor Giampietre, of Pavia, carrying masts and sails, and another by a French mechanician, M. Ader, with two motors, each of 20 h.p. All these machines, however, were far outdone by a monster airship built by Count Zeppelin on the Bodenzee, Wurtemberg. This leviathan, which was cigar-shaped, was 420 feet long, and ingeniously constructed with a number of compartments, designed to prevent the gas from unduly collecting at either end. A pair of petrol motors, capable of driving four-bladed propellers at 1,000 revolutions a minute, were installed, and all was in readiness for trial by the summer of 1900. Like many another colossal undertaking, it met with no ultimate success, and a breakdown caused a collapse of the very costly affair.

This same year saw many strenuous efforts to build a really navigable balloon, and to achieve something approaching to a predetermined flight. The principal cause for this activity was the offer by M. Deutsch of a prize of 100,000 francs to any aëronaut who, starting from the Aëro Club at Longchamps, would sail round the Eiffel Tower and return to his starting-point in the space of half an hour. This offer speedily brought fresh competitors into the field, among whom must be mentioned the names of Feedoroff, Dupont, and Danilewsky. M. Rose experimented on new lines with an airship consisting of two elongated vessels carrying between them the car and motive power. Santos Dumont again and again competed for the prize, constructing one ship after another, regardless of cost. One of his most notable attempts was made with a cigar-shaped balloon 110 feet long, and carrying only a single motor of 15 h.p. In October he fulfilled the conditions of the competition in all ways save that he exceeded the time limit by little more than half a minute.

Many other fresh inventions now began to be brought forward. Herr Kress constructed a flying machine resembling an ice-boat, which he designed for Arctic travel. M. Sutor invented another, intended, when required, to float on water. Mr. W. Beedle designed a navigable balloon which should regulate vertical motion without the need of ballast. More recently, Mr. T. H. Bastin has endeavoured to make a power-driven machine imitate the natural flight of birds.

A sad and sudden gloom was thrown over aëronautical enterprise just at the period of its greatest activity by the tragic fate of M. Auguste Severo, another eminent Brazilian, who sought to emulate the success of Santos Dumont. Constructing his airship on somewhat similar lines, he made the fatal mistake of insufficiently shielding the gas envelope, and keeping it well removed from the neighbourhood of the motor. He was unskilled in practical aëronautics, and in his initial flight, when

at a height of half a mile over Paris, the balloon caught fire, and, with Severo and M. Sachet as passengers, was dashed to pieces. Baron Bradsky, of Austria, a few months later, met with a very similar fate in a somewhat similar balloon.

It was in the summer of 1902 that practically the first English airship was fairly launched into the skies. This was the invention of Mr. Stanley Spencer, a member of the well-known firm of aëronauts, in whose workshops (Figs. 4, 5 and 6) the machine was built. The gas envelope, which was cigar-shaped, measured 75 feet in length. The framework and car were of light but strong bamboo, and a screw propeller was driven by a petrol motor, which, for safety, was placed in the prow, and as far as possible from the safety valve. There was also an ingenious arrangement for introducing air at will into the balloon to regulate the lifting power. A series of preliminary trials through the summer terminated in a journey from the Crystal Palace to Harrow, during which the direction of the vessel was shown to be under considerable control. Subsequent bold efforts to reach St. Paul's from the Crystal Palace, and to circle round the cathedral, were of a yet more successful character.

Following close on these trials, others on a more ambitious scale were carried out by the Brothers Lebaudy, whose airship was upwards of 100 feet in length, driven by two propellers, operated by a petrol engine of 40 h.p. Several satisfactory journeys were made, but, as in previous experiences, a calm atmosphere was an essential of success.

Photo: Messrs. Campbell & Gray, Cheapside, E.C.

FIG. 7.—MR. F. S. CODY AND HIS KITE.

Mr. Cody is to be seen on the left of the picture.

After a twelvemonth of inactivity so far as public exhibitions were concerned, Santos Dumont in 1903 came before the world again with an airship gem of only 49 feet length, egg-shaped, and driven by a miniature engine of 3 h.p. The weight of the whole apparatus was reduced to 300 lb., and in still air the craft acted in perfect obedience to the operator's will.

For many months a navigable balloon, which secured the attention of the War Office, has been under construction at the hands of Dr. Barton. Its chief characteristics are large size and weight, and proportionately powerful engines. But for actual size Mr. Stanley, of San Francisco, makes the chief claim with an airship built of aluminium, 228 feet long, and containing no less than 240,000 cubic feet of gas.

The principal attempts hitherto made by flying machines and navigable balloons have now been sufficiently dealt with, and it remains to glance at some notable endeavours in other directions by which it has been sought to add to our knowledge of the realm of air, and to devise modes for its subjection to the hand of man. The word " *aëro-plane* " is of very constant use in modern aëronautics. According to its most recent definition, it is used to designate an " apparatus that is heavier than air, and formed of one or more sustaining planes, with one or more propellers, on a horizontal axle." Its simplest form is to be seen in the kite, of which there are two principal varieties—the sail kite, and the cell or box kite (Fig. 8). All the most efficient kites are tailless, and those of the sail form are commonly either bowed away from the wind to prevent any chance gust getting behind and upsetting them, or otherwise they are constructed to bag into hollows symmetrically, and the wind, filling, these hollows as it would a bellying sail, holds the apparatus in equilibrium. A cell kite, each cell generally resembling a box without top or bottom, gains steadiness and efficiency by presenting several planes to the wind. Mr. S. F. Cody, whose kites have an addition of what may be described as outspread wings and fins, are so powerful and steady as to lift a man with safety. The invention of aërostats of this description has undoubtedly aided in the proper construction of flying machines. A well-designed kite breaking loose with a length of line dragging on the ground has been known to behave as a true flying machine, traversing the air for a long distance before finally settling to earth. In Lord Rayleigh's opinion, the main problem of the flying machine is that of the aërial plane. " Supposing," he says, " a plane

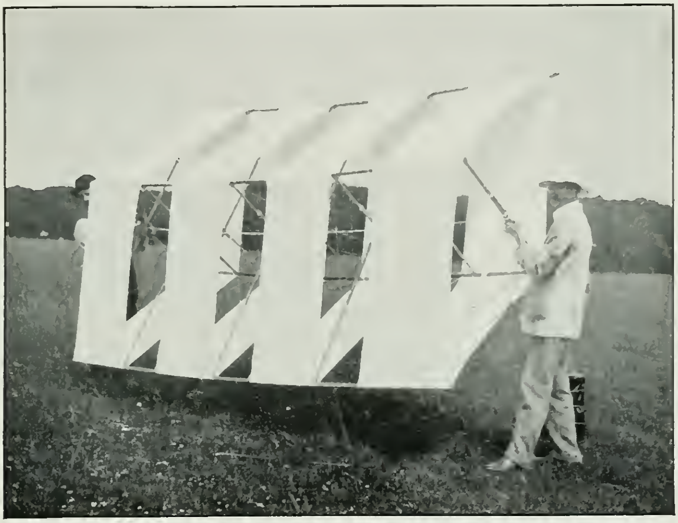


Photo: Messrs. Campbell & Gray, Cheapside, E.C.

FIG. 8.—A BOX KITE USED BY MR. F. S. CODY.

surface to be falling vertically at a rate of four miles an hour, and also moving horizontally at a rate of twenty miles an hour, it might have been supposed that the horizontal motion would make no difference to the pressure on its under surface which the falling plane must experience. We are told, however, that in actual trial the horizontal motion much increases the pressure under the falling plane, and it is this fact on which the possibility of natural and artificial flight depends."

This paper would be incomplete without some reference to a few other of the most notable exploits of recent aëronauts. In August, 1900, Captain Spelterini filled a balloon with hydrogen on the top of the Rigi, and succeeded in traversing regions of the Alps inacessible to man. He descended in safety on a peak 5,000 feet high. The same autumn open ballooning races on a grand scale were inaugurated at Vincennes, none, however, but foreigners competing. Count de la Vaulx, who was declared winner, covered no less than 1,193 miles in less than thirty-six hours. A recent performance of the same aëronaut was a voyage from Paris to Hull. In the autumn of 1899 the writer, accompanied by his daughter and Mr. Stanley Spencer, established a record in English ballooning by maintaining a lofty sail of ten hours' duration. The object on this occasion was to obtain a view from aloft of the expected shower of Leonid meteors. The balloon was not under control, and had to be left to settle to earth. The speed of the wind was considerable, and, the earth being constantly obscured by cloud, it will always remain a mystery over what course the balloon was carried, and by what providential circumstances it was not borne far out to sea.

Photo: Messrs. Campbell & Gray, Cheapside, E.C.

FIG. 9.—WINDING UP NO. 7 IN THE RECENT KITE-FLYING CONTEST AT FINDON, NEAR WORTHING, JUNE 24TH, 1903.

THE MECHANISM OF A MOTOR-CAR.

BY THE EDITOR OF "THE AUTOMOBILE."*

THE motor-car, now almost as well known by the name "automobile," is an ancient invention; but in its present form it exemplifies the very latest development of mechanical science. As far back as the thirteenth century Roger Bacon speculated upon the possible employment of road engines, and a century or so later cars were driven by spring power in Germany, and by the use of sails in the Netherlands. The wind-driven car—only by courtesy can it be styled an "automobile"—has survived to this day on the continents of Europe and America in the form of ice yachts, these being boat-like vehicles mounted on iron runners, and made to scud before the wind, to tack and to turn about with all the facility and grace of a smart sailing yacht.

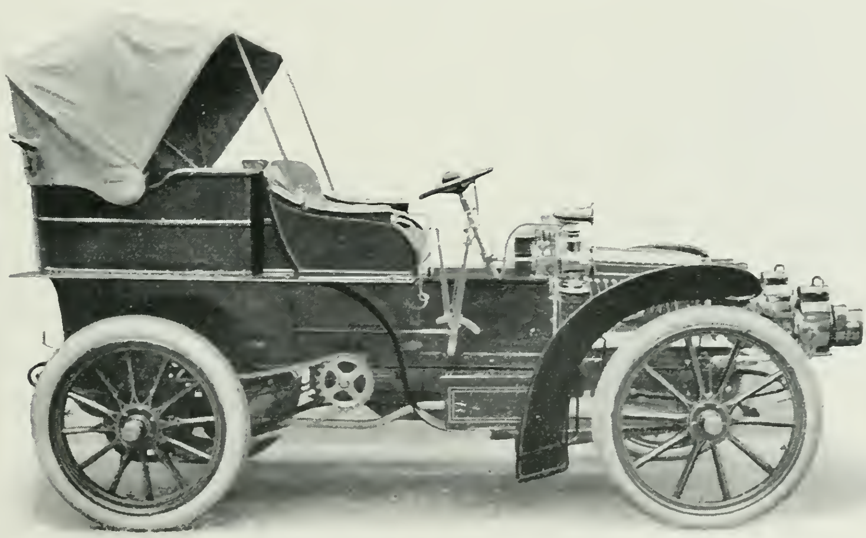


FIG. 1.—THE NAPIER PETROL CAR.

The history of the automobile cannot be pursued further here, but mention must be made of Gottlieb Daimler's invention of the high-speed petrol motor in 1885, but for which the motor-car industry of to-day could hardly have come into being.

Three sources of energy are in common employment for automobiles. Put in their order of popularity, they are petrol, steam, and electricity; but some time in the future this will be reversed, unless, indeed, some motive power better than any of the three is introduced.

Take a glance at an ordinary petrol car of standard make while it is at rest (Fig. 1). It has a well-upholstered, beautifully finished body, with perhaps a glittering "bonnet" in front, but there is no

* "The Automobile," by Paul N. Hasluck. A Practical Treatise on the Construction of Modern Motor-Cars—Steam, Petrol, Electric and Petrol-Electric. Published by Cassell & Co., Ltd.

external evidence of how it works, save, perhaps, two side chains, which, when the car is in motion, drive the rear wheels. Assume the body-work and the "bonnet" to be removed, and this is what you see: a longitudinal frame of wood or channel steel, perhaps of steel tubes, supported on springs over two axles (Figs. 2 and 3). In the front, where previously it was hidden by the "bonnet," is an engine, called in automobile parlance the motor. By its side is a gas-making device, known as the carburetter, which may act in various ways, but whose principle is the bringing together of air and petrol, so that the former vaporises and absorbs the latter and produces an explosive gas. Petrol, be it said, is a distillation of crude petroleum obtained at a temperature between 70° and 100° C. (158° and 212° F.), and is variously known as *motor spirit*, *essence*, and *gasoline*. The gas, known as the "mixture" or charge, passes through a pipe to the motor, in whose cylinder or cylinders it is burnt under pressure, being ignited by an electric spark or by a hot tube. The combustion yields a large volume of hot gas, whose expansion in the cylinder pushes out a piston connected by a rod to a crank-shaft. As will be explained later, there is only one power stroke in two outward strokes of the piston, and so three strokes in four (one outward and two inward strokes) are not giving any impulse to the crank-shaft. Indeed, they use up some of the energy that the working stroke puts into that shaft. For this reason, the action is in a series of jerks, and is intermittent, and the cycle of operations could not be carried through were it not for the energy stored up in a large and heavy flywheel firmly secured to the crank-shaft on its inner or rearward end.

As a rule, the flywheel contains a friction clutch, which transmits the motor power to a short shaft lying longitudinally in the centre line of the car. At this point there is considerable variance in practice, but in nearly all cases the shaft drives a system of gearing, by which means changes in the speed at which the car is travelling are obtained. This is explained later. From the rearward end of the change-speed gear-box protrudes a short cross-shaft, whose ends project over the main frame of the car and carry chain-wheels, technically known as sprockets, one on each side of the car. Strong, heavy chains connect these sprockets with other sprockets firmly

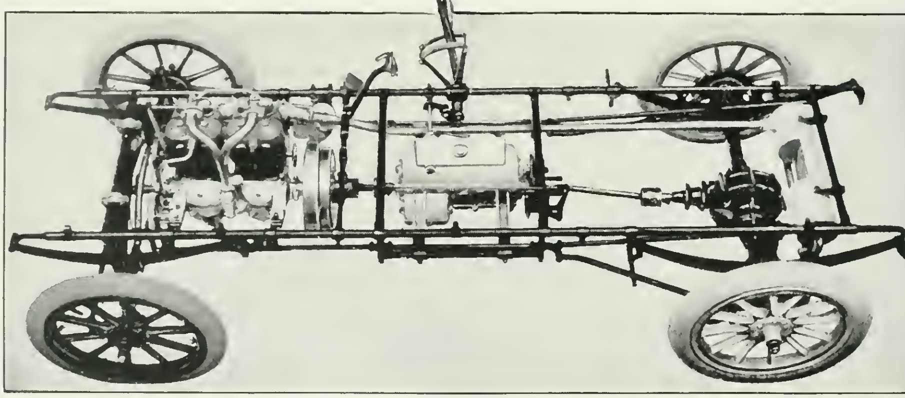


FIG. 2.—SHOWING THE MECHANISM OF A VELOX PETROL CAR WITH THE "BODY" REMOVED.
The motor is on the left hand.

secured to the spokes of the rear road wheels, which wheels revolve freely on fixed axles, as in a horse-drawn vehicle. It follows that when the motor is acting, its power is transmitted through the main clutch to the road wheels. Often side chains are not used, and in that case there is no cross-shaft protruding from the change-speed gear-box ; instead, a longitudinal shaft (Fig. 2) projects from the box at the rear, and drives the rear axle by a system of bevel gearing, to be duly explained. The big difference between the two systems is, with side chains the axles are fixed and the road wheels revolve quite loosely upon them, the motor power being transmitted direct to the wheels ; with a longitudinal driving shaft and bevel gearing the axle is mounted so as to revolve freely in bearings, whilst the road wheels are keyed upon the axle and revolve only when the axle revolves ; the motor power is then transmitted to the axle, which is distinguished as " live."

The elements and the mechanism whose functions have been summed up so briefly above may now be described separately and in detail.

We will consider the motor first. This is of the " internal combustion " or " explosive " type, and the user of a gas-engine will easily comprehend it. It is practically a gas-engine with provision for making its own gas. It acts by sucking in (*inducing*) a charge of gas, compressing it, firing it, and then clearing out the combustion products, an operation known as *scavenging*, in readiness to receive the fresh charge. Suppose we have a steel cylinder fitted with a piston ; it is open at one end, and at the other is closed, except for two little holes, in each of which a valve works. One hole only is in communication with a gas supply, and the valve in it opens only under the suction of the piston, the valve in the other hole being worked by a suitable mechanical arrangement. The piston is connected by a rod to a crank-shaft to which is secured a heavy flywheel. Projecting into the cylinder is a tube kept hot by an outside flame, or, instead, there is an electrical arrangement for producing a spark at the required moment. We have now the simplest of internal combustion engines.

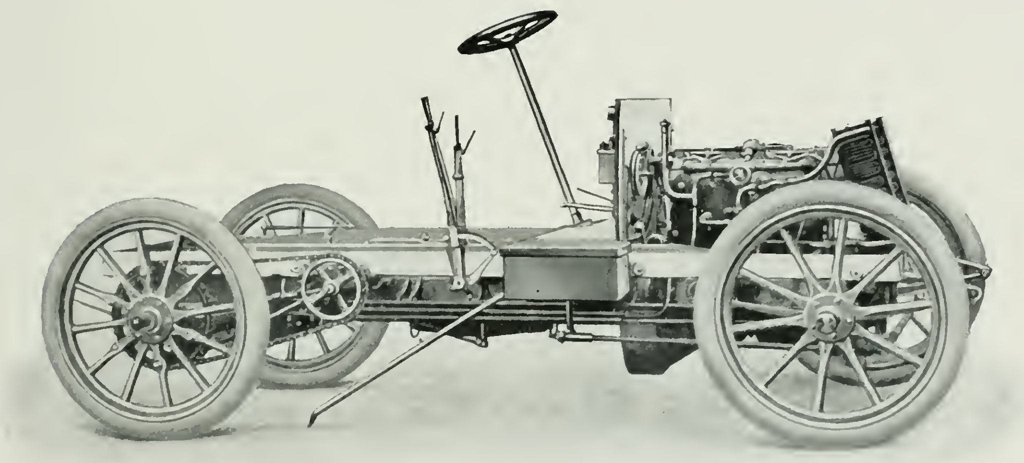


FIG. 3.—ELEVATION OF BRUSH PETROL CAR WITH " BODY " REMOVED.

Assume the piston of this experimental motor to be pushed in as far as it will go: say, an inch from the end of the cylinder.

For a moment ignore the valve in the hole open to the atmosphere, which we will call the *exhaust*. The other valve—the inlet or induction valve—is shut. With the hand rotate the flywheel so as to withdraw the piston from the head of the cylinder. As the piston moves, the inlet valve opens under the suction and admits mixed gas and air. In time the piston reaches the end of its outward travel, and the cylinder is now full of gas. When the piston begins to return, the suction, of course, ceases, and the inlet valve closes. Keep that flywheel moving and the piston will continue its inward stroke, and will compress the gas until it reaches the end of its inward travel (the distance from one extreme to the other is known as the "piston stroke"). The gas now occupies but a fraction of the space it did before compression. Keep the flywheel moving, and just as the piston is beginning its second outward stroke, pass through the charge of compressed gas an electric spark. Where there is a hot tube igniter, as in nearly all old-style petrol motors, the gas will automatically ignite, according to its richness and the amount of compression. The combustion—some authorities hold that it is an explosion—is very rapid, and its product is a mass of hot gas, whose volume grows with great rapidity. What is the result? The piston is pushed out with great force and suddenness, and by means of the connecting rod and crank-shaft sufficient energy is given to the flywheel to cause it to revolve a number of times without any manual help. But the cycle of operations is not yet complete. As yet the piston has performed three strokes—two outwards, one inwards; and now, as the flywheel revolves, it is obliged to return and perform the fourth stroke. Remember that the inlet valve opens only under suction, and so now is closed; also that the cylinder is full of burnt gas which has expanded and done its work, and which must now be got rid of. The mechanical device in connection with the other valve now comes into play, and as the piston makes the fourth stroke of the cycle the exhaust valve opens, and the cylinder is "scavenged" of the used gas. Then the exhaust valve closes and the cycle of operations begins again, the momentum acquired by the flywheel being sufficient to move the piston to and fro until the next working stroke occurs, and, of course, there is besides a big surplus of power. This is the principle on which the majority of gas-engines, oil-engines, and petrol motors work. Here is a synopsis of the operations in a four-stroke cycle:—

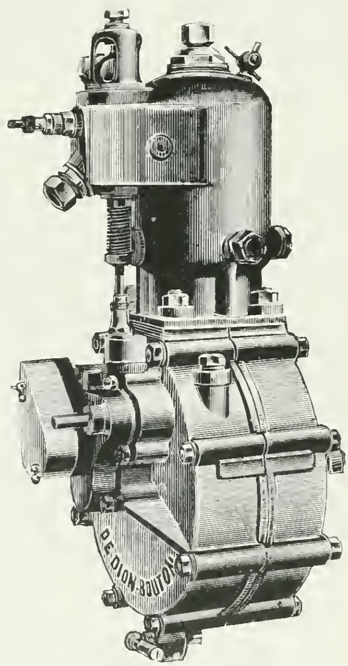


FIG. 4.—DE DION-BOUTON ONE-CYLINDER MOTOR.

First forward stroke of piston is the suction stroke; and the explosive gas, or "mixture," is admitted. Inlet valve open; exhaust valve closed.

First return stroke of piston is the compression stroke; the charge is compressed. Inlet valve closed; exhaust valve closed.

Second forward stroke of piston is the working stroke; the charge has been

ignited. Inlet valve closed; exhaust valve closed.

Second return stroke of piston is the "scavenging" stroke; the gases of combustion are expelled. Inlet valve closed; exhaust valve open.

Petrol motors work at great speeds (between 500 and 1,500 revolutions of the flywheel per minute), and the multiplicity of ignitions or explosions would raise the cylinder to red heat, and the piston would seize and refuse to work, were not means provided to keep the walls of the combustion chamber and cylinder cool. In small motors it suffices to provide radiating ribs or flanges (Figs. 4 and 5); but for larger motors the combustion chamber and cylinder have to be made with double walls, between which water, constantly changed, can circulate. The water is itself cooled in thin metal tubing covered with gills or flanges, which radiate the heat into the rushing air when the car is in motion. Cooled as the motor is, lubrication must be copious, otherwise the piston quickly seizes, and the oil used must remain uncharred at high temperatures.

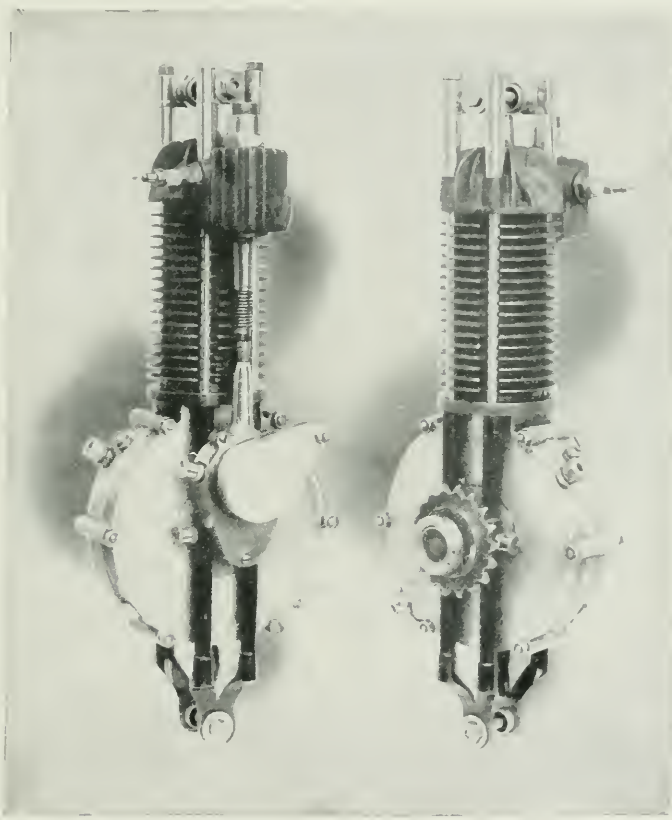


FIG. 5.—TWO VIEWS OF THE HUMBER CYCLE MOTOR.

Now let us see how the principles of operation described above are applied in an actual motor. Take the English-Daimler modern 12-h.p. motor as an example. This is shown in half side elevation and half vertical section by Fig. 6. First there are four steel vertical cylinders communicating at their lower and open end with the crank chamber B, and

working up and down in each cylinder is a piston V and connecting rod X, the last-named giving motion to a crank-shaft C, on which is the heavy flywheel A. The gas-maker or carburetter is shown at Y, and from it leads pipe Z to a little chamber in the head of each cylinder containing the inlet or induction valve H. The valve normally is shut, but under suction it opens, a special spiral spring, as shown, closing it again immediately the suction ceases. In some motors the valve is operated by a mechanical arrangement similar to that employed for the exhaust valve J. When this last-named valve is open, it being often lifted off its seat, the gases of combustion pass down into pipe I, and are led away to a metal cylinder in which is a great number of small holes. This appliance, known as the silencer, exhaust box, or muffler, has the effect of deadening the noise of the exhaust, which is very great.

Note the simple means by which the exhaust valve is worked. It is supported on a stem held in a guide S, and at its lower end is a little wheel, which is in contact with a cam W. This cam is secured to a shaft Q driven by the two toothed wheels T U from the main crank-shaft at exactly half its speed; that is, for every two revolutions made by the main shaft C, the half-speed shaft Q makes only one. The cam is an eccentrically shaped piece of steel, and, as it revolves, its projection strikes the little wheel above it and lifts the valve stem, this, of course, opening the exhaust valve above. As the cam revolves only once for every two revolutions of the flywheel, it follows that the exhaust valve is opened only once during each cycle of four piston strokes. The cam is so shaped and is

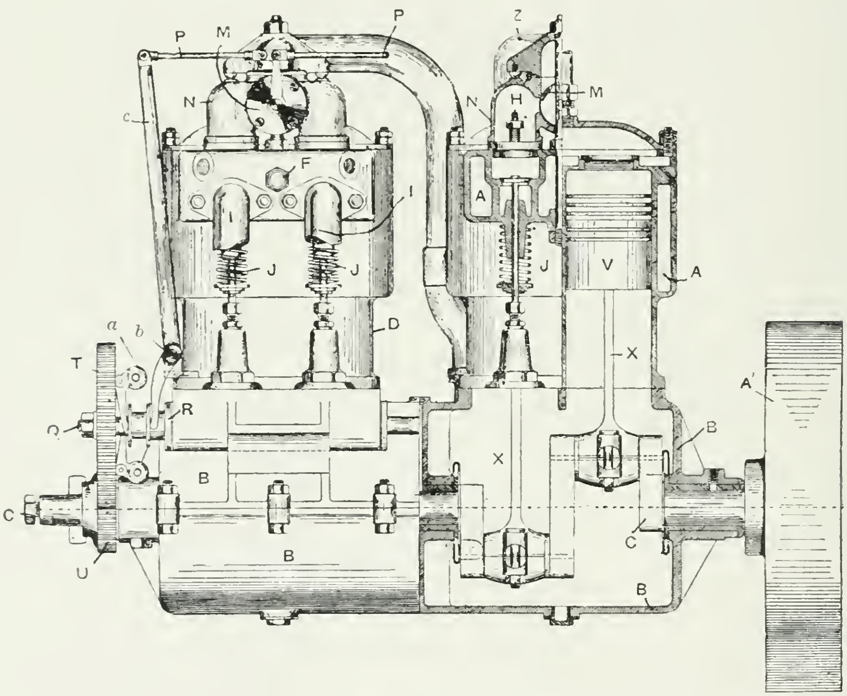


FIG. 6.—MECHANISM OF A DAIMLER 12-H P. MOTOR.

Principal References:—A', flywheel; B, crank chamber; C, main shaft; H, induction valve; J, exhaust valve; Q, half-speed shaft; T, U, toothed wheels; V, piston; W, "cam"; X, connecting rod; a, b, c, and P, governor and governing mechanism.

secured on its shaft in such a position that the valve is opened at exactly the right time and for the correct period.

To provide for the ignition of the explosive mixture, sparking plugs screw into the walls of the valve chambers. To make the construction of such a plug clear, study Fig. 7, which is a cross section of a de Dion-Bouton make. It is cylindrical in form; A is a screw plug fixed into the wall of the combustion chamber from outside; B is a piece of porcelain acting as an insulator. An accumulator, a dynamo, or magnetic machine supplies the electric current, which is intensified in a coil with contact-breaker, of which one terminal is connected to the plug terminal C, and so to the sparking point D, and the other to the cylinder wall, and so through the plug A and the sparking point E. The porcelain is kept in place by plug F. The current jumps from D to E, and in so doing produces a spark of sufficient intensity to ignite a compressed explosive mixture.

In order to be efficient, the motor cylinder must be kept cool, so water circulates in the jacket.

The motor must not race at a speed detrimental to its efficiency and destructive to its mechanism, and so on all high-class makes there is an automatic governing device. The English-Daimler mechanism is typical of many. On the half-speed shaft Q, already described (Fig. 6), is a governor, *a*, and the greater the speed of the motor the wider do the governor balls spread out, these pressing the trigger *b* sideways, and by means of rods *c* P partially closing a throttle valve M in the casting N. The effect is to reduce the quantity of explosive mixture admitted from the carburetter into the combustion chamber.

The gas-maker or carburetter remains. It may have many forms, but one of the best is the English-Daimler, known technically as a "float-feed spray carburetter."

Some idea as to the relation between power and dimensions in a petrol motor may be gained from the fact that the English-Daimler motor gives twelve horse-power when running at a speed of 930 revolutions per minute, the internal diameter (bore) of each of the four cylinders being 3.38 inches, and the piston stroke 3.93 inches.

The most important feature of the petrol automobile—the motor—having now been described, attention may be devoted to the transmission or running gear.

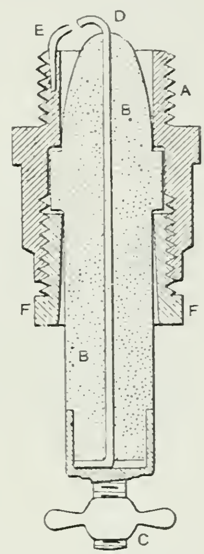


FIG. 7.—DE DION-BOUTON IGNITION PLUG

A, screw plug; B, porcelain insulator; C, terminal; F, screw plug; D, sparking point; D-E, length of spark

The friction clutch is the medium through which the power of the motor is transmitted to the running gear. In the most simple types, the motor flywheel is hollowed out cone-fashion to form the "clutch shell" or "female member." The shaft to be driven ends in the "male member," this being a disc having a coned or bevelled edge, often leather-covered, which exactly fits the coned hollow in the flywheel. When one is inserted into and pressed against the other by the action of a spring, sufficient friction is set up for the female part—the flywheel—to drive the male part without any slipping between them, whilst driving contact can be destroyed in a moment merely by withdrawing one from the other. At times a little slipping is desirable, and then the two parts are only lightly pressed together. Depressing a pedal puts out of action the clutch, which has a strong spring.

Change-speed gear is a necessity in a petrol car. The petrol motor is not flexible, as is the steam or electric motor; that is, it does not accommodate itself to changes of speed. Much improvement has been effected recently in this connection, but still there must be a means independent of the motor of altering the speed at which the car travels. This is not necessary with steam or electricity. A petrol car may have two, three, or four mechanical speed changes. When a big toothed wheel drives a small toothed wheel, the latter revolves at a proportionately greater speed than the former, and *vice versâ*. Thus wheels differing in diameter and caused to slide in and out of mesh with a revolving wheel on a fixed centre revolve each at a different speed. This is the principle of the Panhard type change-speed gear employed on the majority of petrol cars.

A motor-car must possess the capability of running backwards, and to effect this a third toothed wheel is interposed in the change-speed gear between one shaft and the other. Two wheels running in mesh together rotate in different directions, but when motion is transmitted through a third and intermediate wheel, the original and the ultimate movements are in the same direction. This is the principle of the reverse gearing, and generally it is the lowest gear of all to which the reverse is applied, so that reverse speed is at the same rate as the lowest forward speed.

Many cars have "live" axles, as has been indicated, and their driving mechanism is different from that in those vehicles typified by the Brush. Fig. 2 is a view of the chassis of the British-built and recently introduced Velox car, which is of a "live" axle type. The steering pillar and hand-wheel are not illustrated, though, of course, they are found fitted in the finished car: but many of the other features will be recognised from the description of details already given. The big difference—apart from the use of a steel tubular main frame instead of a wooden one, stiffened with steel plates—is the mechanism employed for driving the "live" rear axle. As usual, the motor drives the change-speed gear through a clutch, but there is no cross countershaft; instead, projecting from the gear box downwards towards the rear axle is a short length of shaft, having at each end a universal joint, so that it can rotate out of line with both the shaft by which it is driven and the one which it drives. This latter is a very short horizontal shaft, on whose end is a pinion with a conical circumference engaging with a bevelled toothed wheel, made solid with the differential gear case. It may be mentioned that the peculiarly shaped box near the differential is the exhaust silencer or muffler already referred to.

The reader who has closely followed this description should now be tolerably familiar with the more prominent features of a standard petrol car. The Napier (*see* Fig. 1) is perhaps the best known all-British car made, its fame dating principally from the Gordon Bennett race of 1902, which was won by Mr. S. F. Edge on a car of that make. Three Napiers ran also in the 1903 event which took place in Ireland, but ill-luck dogged every one of them, and the race was won by a German on a Mercédés, the famous car made by the German-Daimler firm. The Panhard is one of the most popular French cars. An example of the manner in which the motor-car is being adapted to meet the many and varied requirements of social life is the Maudslay convertible omnibus, and another is the Motor Manufacturing Company's car with roof and curtains (Fig. 9).

Steam and electric automobiles must have mention, but the bulk of the space at our disposal has been given up to the

petrol car, which is far and away the most popular, though, strangely enough, the least understood. The steam boiler and engine are common enough to-day, and most people have some idea of how they work. In the steam automobile, as a rule, the boiler is heated by a petrol or paraffin burner, the liquid before combustion having been vaporised and sometimes mixed with air. The boiler may be fire tube, water tube, or "flash," the last-named having been popularised by Léon Serpollet, and consisting of a length of small-bore tube, through which water is forced, in actual contact with the burner heat. The steam supplied by the boiler passes direct to the engine cylinder, in which the expansive effort of the steam is employed to push out a piston. It is not usual to employ either a friction clutch or change-speed gearing. The purpose of the former is answered by cutting off or turning on the steam supply to the engine, and the purpose of the latter by varying the amount of the steam supply. Generally a sprocket on the motor crank-shaft is merely connected with another on a "live" rear axle by a chain, as in Fig. 8. Sometimes a condenser is fitted with the object of converting the exhaust steam into water, which can then be used over again, but this practice only gives satisfactory results when a "flash" boiler is employed, as with ordinary boilers the steaming efficiency falls when the water contains lubricating oil. The oil separators employed never thoroughly remove all traces of the oil from the used water. The "Locomobile" is a light steam car, typical of many American motor vehicles.

Electricity is the subject of other papers in CASSELL'S POPULAR SCIENCE, and the principles of electric motors and accumulators are there set forth. These having been grasped, there is nothing in an electric car that cannot be understood easily. A number of accumulator cells is divided up into several batteries, each contained in a case or box; they, of course, require to be charged from a dynamo or other source of electrical energy. The current yielded by them when the proper connections are made energises an electric motor geared to a differential countershaft, from which the road wheels are driven, as in the petrol car already described. But in another method, now becoming general, there are

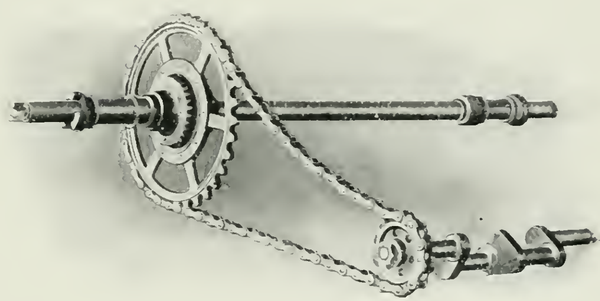


FIG. 8.—SERPOLLET CHAIN DRIVE.

two motors, one on each half of the divided "live" rear axle, thus rendering it possible, if desired, to dispense with the differential or balance gear, which often is a source of trouble. Typical electric cars are the City and Suburban victoria and the Waverley "Runabout."

An electric car need have no clutch or change-speed gearing, these being replaced by a controller. This acts by establishing various couplings between the different parts of the electric mechanism, such as accumulator terminals, motor brushes, armature, and field-magnet windings, and they are getting familiar to the public owing to their adoption on electric tram-cars. A typical controller is a cylinder of insulating material round which longitudinal strips and plates of metal are fixed in a certain order, whilst a number

of insulated contact arms or spring blades press on the strips and are connected with the batteries and motors. To illustrate the manner in which changing the connections changes the speed, it may be said that in one type of Kriéger electric car employing two compound-wound motors, the batteries are connected in parallel and the motors in series to obtain slow forward speed. Put the batteries in series also, and there is higher speed. By cutting out the series field coils and so weakening the field-magnets, there is a further increase of speed, and the motors become shunt-wound. When running at more than their normal speed, as when going downhill, the motors act as dynamos and re-charge the batteries to some extent; this is known as a "recuperative effect." The maximum power and speed are developed when the batteries are in series and the motors in parallel.

The difficulty of obtaining accumulators that will supply current for long journeys without re-charging, together with the high cost of motive power, has hitherto been the greatest obstacle to the more extensive use of electric cars, which are the easiest to drive, the simplest, and the least likely to get out of repair, of all forms of self-propelled carriages.

But a new type of car—the petrol-electric—gives promise of combining the ease of operation of the electric car with the self-contained motor of the petrol car. In the new system, a petrol motor drives a dynamo which, besides energising electric motors on the wheel axles, gives its surplus current to accumulators which assist the progress of the car uphill, and which alone are quite capable of propelling the car for a short distance should the petrol motor fail.

Readers who want an exhaustive and authoritative technical treatise will find it in "The Automobile," by P. N. Hasluck.

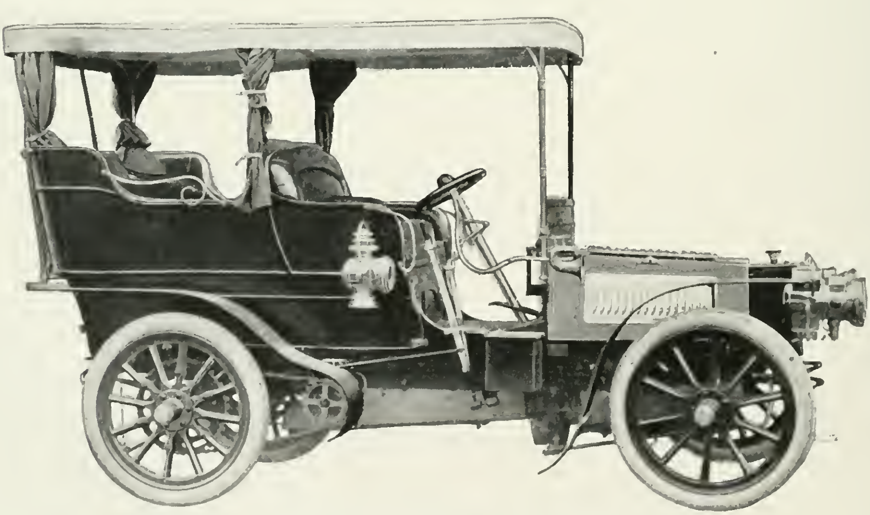


FIG. 9.—MOTOR MANUFACTURING COMPANY'S CAR, WITH HOOD.

DIAMOND IN CLAY.

FROM A SPECIMEN IN THE NATURAL HISTORY MUSEUM, SOUTH KENSINGTON.

DIAMONDS.

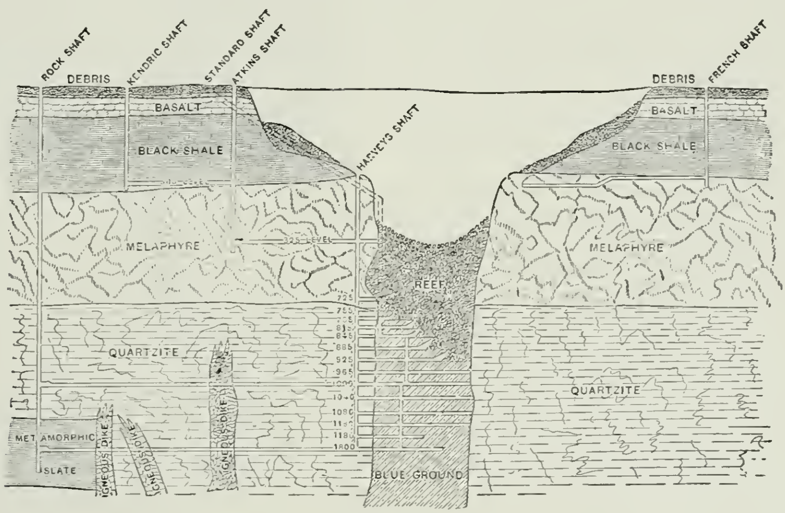
NO less keen an observer than Shakespeare has told us that

"Dumb jewels often in their silent kind"

are able to effect "more than quick words."* It is the purpose of this article to put a tongue into some of these "dumb jewels," and to listen to their scientific teachings. Let us endeavour to show that there is something in them worth noting beyond mere beauty and glitter, to reveal, in short, their chemical and physical history. It is with only one stone, however, that we will at present deal; and as the most typical example of a precious stone we naturally select the diamond.

By far the greater number of mineral substances, and not a few artificial products, are capable, under favourable conditions, of assuming definite shapes, always symmetrical and often extremely beautiful. Water, for instance, when allowed slowly to freeze into a mass of rigid ice, exhibits this tendency. Instead of solidifying into a formless mass, it tends to branch out into graceful shapes, which often mimic the spreading frond of a fern. Who, indeed, has not admired upon his bedroom window those beautiful

"Ice ferns on January panes
Made by a breath"? *



(FIG. 1.)

SECTION OF KIMBERLEY MINE
LOOKING EAST
100 50 0 100 200 300 400 500 FT.
SCALE

This power of solidifying in regular shapes is known as *crystallisation*. It is not, however, every kind of matter that enjoys this power. Take, for instance, a piece of glass, and mark how different its structure from that of ice; observe, in fact, the difference between the "January pane" and the "ice ferns" which cling to that pane. Sufficient heat will fuse the glass to a clear liquid; but when this liquid

* *The Two Gentlemen of Verona*, Act III., Sc. 1.

* Tennyson's "Aylmer's Field."

cools it solidifies without any tendency to shoot out in one direction rather than in another. It is true that, under exceptional conditions, glass may be induced to crystallise; but then its characters are

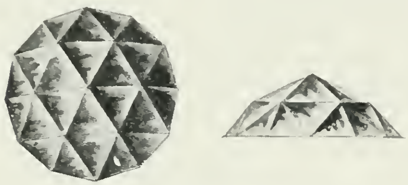


FIG. 2.—A ROSE-CUT DIAMOND.

so greatly changed that the glass loses its glassiness, and is hence said to be *devitrified*. Under all ordinary conditions the mass of glass is without regular form. Some kind of shape, of course, it must possess, like every other solid body; but it is an irregular or accidental shape, lacking all symmetry and definiteness. So far, indeed, from being anything like a crystal, it is more like

"That other shape,
If shape it may be called, which shape had none."*

Bodies which are thus destitute of definite form, save that which is given to them from without, are said to be *amorphous*; while those which are capable of spontaneously assuming regular form are described either as *crystallised* or as *crystalline*, according as the shape is well marked or merely confused—thus, sugar-candy is crystallised, and loaf-sugar crystalline The diamond is generally found in well defined, symmetrically shaped, solid forms, or *crystals*.

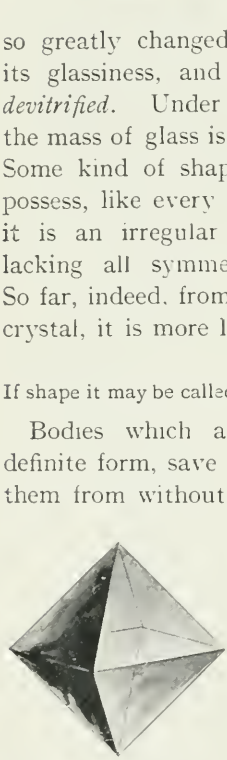


FIG. 3.—A REGULAR OCTAHEDRON — A TYPICAL FORM OF DIAMOND

And here we may remark that it is not a little curious to trace this word "crystal" to its source. Originally we find it applied to that clear and hard

* "Paradise Lost."

substance which is still known as *rock-crystal*—a mineral which was formerly used to a large extent in jewellery, but which is now chiefly employed in the manufacture of spectacle lenses, when it is termed "pebble." This mineral was found by the ancients in the clefts of those granitic rocks which rise into sharp peaks high above the snow-line in the Alps. So clear, so ice-like, were these crystals, that it seemed fair enough to assume that they were nothing but intensely frozen water—an assumption which was fortified by their frequent discovery in the neighbourhood of Alpine

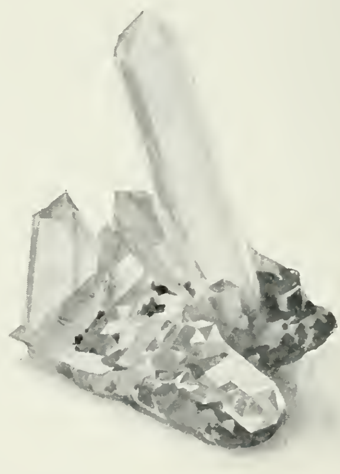


FIG 4—A PIECE OF BRAZILIAN ROCK-CRYSTAL.

Rock-crystals are not infrequently mistaken for diamonds.

glaciers. And thus it came to pass that the Greek word for ice—*crystallos*—was applied to this substance.

That this view of the origin of rock-crystal was seriously held by the philosophers of antiquity is clear from a passage in Pliny, where we are told that this crystal "is found only where the snows of winter freeze hardest; it is certain that it is ice, whence also the Greeks gave it the name."* Nor is there the slightest doubt that he refers here to

* "Hist. Nat.," XXXVII. 9.

rock-crystal, for a little farther on he confesses that "it is not easy to say why it is born with six angles and six faces." This description of the six-sided forms agrees exactly with the common crystalline

FIG. 5.—THE DE BEERS DIAMOND.

This huge stone, which weighed 428½ carats, was found on March 28th, 1888.

characters of rock-crystal, as shown in Fig. 4.

Up to within about a century ago the diamond was regarded as simply a peculiar kind of rock-crystal: nor, indeed, is the difference always understood even at the present day. It has occasionally happened that an emigrant has thus been bitterly deceived after having travelled, it may be, thousands of miles with his supposed treasures. Ignorant of minerals, he has counted himself fortunate in having picked up, in the bed of a stream in some unknown land, a number of beautiful little crystals, which are as clear as the purest drops of water. If he looks at them carefully, he observes that every edge is as sharp and every face as smooth as though it had been cut by the most skilful of lapidaries; moreover, if he touches these faces with a hard steel file, he fails to make the slightest impression upon them. What, then, can such stones be but diamonds?

The most superficial comparison of the crystalline forms of the diamond with those of rock-crystal is sufficient, however, to set all doubt at rest. It is true that both the rock-crystal and the diamond present symmetrical shapes, but the kind of symmetry is very different in the two cases. Look at the rock-crystal in Fig. 4, and observe that the column has six sides to it, and that the cap has also six sides. Now turn to the crystal of diamond in Fig. 3, and mark the difference. Here is a solid, made up of an upper and a lower half, each bounded by four faces, but showing nothing like the six-sidedness of the rock-crystal.

It must not be supposed that every crystal of diamond is as simple as that represented in Fig. 3, which we have hitherto taken as our type. The forms which the diamond assumes are, indeed, very various, and often exceedingly complex, but these forms are all governed by the same law of symmetry, and are all related more or less closely to the cube. They belong, in fact, to one common group or system.

Whatever form the diamond happens to possess in its native state, it may always be split with ease into an octahedral shape, like that represented in Fig. 3.

FIG. 6.—ANOTHER FAMOUS DIAMOND—THE EGYPTIAN PASHA.

This property of splitting in a definite direction is known as *cleavage*, and is a property enjoyed by most crystallised substances. If a body be uncrystallised, such as a piece of glass, it exhibits no tendency to split in one direction rather than in another; but if it be crystallised, the case is very different, for the effect of a blow is then, not to shiver it into irregular fragments, but to split it along definite planes. The diamond

possesses an *octahedral* cleavage—that is to say, it splits along planes which correspond to the faces of a regular octahedron.

FIG. 7.—DIAMOND-SPLITTING.
This is the first stage in dressing a stone. The diamond is embedded in a matrix of resin and brick-dust, mixed, and attached to the end of a small wooden rod. The hammer is the steel rod in the operator's hand.

This property of cleavage is taken advantage of by the diamond-cutter in the preparatory operation of dressing a diamond. If the rough stone be not already in the form of an octahedron, it can be readily reduced to that form by skilfully delivered blows. Or if it be desired to remove a flaw or other imperfection in the stone, the diamond-splitter can detach a slice by a single tap. The experienced eye readily traces the direction in which a fragment may be split off with ease, rapidity, and certainty. To effect this operation the diamond-splitter —who is represented at work in Fig. 7—embeds the stone in warm cement, composed of a mixture of resin and brick-dust, and attached to the end of a small wooden rod. Part of the stone is free, and on this part the operator traces, by means of another diamond, the direction in which he intends to effect the cleavage. Then, supporting the rod of wood in an upright position, by insertion in a hole in a block of lead, he places a steel blade in the notch which has been cut by the second diamond, and strikes a sharp blow on the back of the blade by means of a little hammer, which is really a peculiarly shaped steel rod. The stone, having been split by a smart tap, is released from its matrix by warming the cement, and is then ready for cleavage in another direction.

After having been duly split, the diamond passes into the hands of the cutter, who skilfully trims it to the shape which it is required to display. This operator embeds the greater part of the stone in cement, carried at the end of a wooden handle, and then rubs the exposed part against another diamond similarly mounted. In Fig. 8 the cutter is seen patiently rubbing the two stones together until the surfaces are sufficiently worn down. The operation is performed over a small box, which catches the dust, this diamond dust being of such value that every grain is carefully preserved.

FIG. 8.—DIAMOND-CUTTING.
Note that the workman wears padded gloves in order to keep up the required pressure without injury to his hands.

It is worth noting the successive stages by which the "cutter"—or, as he might more appropriately be called, the "rubber"—is able to develop the form best adapted to display the beauty of the diamond. Let us see, for example, how he could cut a brilliant out of an octahedron. The first step is to grind down one of the four-sided points, or solid angles, to a flat surface, which is called the *table* of the diamond. Thus, if A in Fig. 10 represent a side elevation of an octahedron, the summit will be replaced by a plane, as shown in B. Then the opposite four-sided point is similarly rubbed down; but this second plane, which is known as the *culet*, is much smaller than the table, as indicated in B. The line which runs horizontally round the stone, between the table above and the culet below, is termed the *girdle*: evidently it is the natural edge of the octahedron separating the upper from the lower four-sided pyramid.

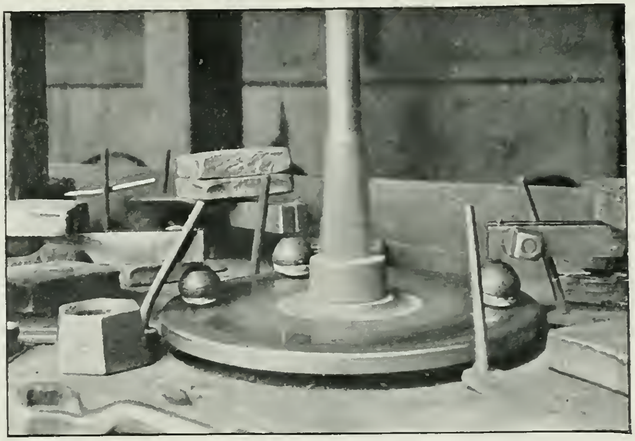


FIG. 9.—THE FINAL STAGE: POLISHING THE STONE.

The wheel here shown is in rapid motion; it is covered with diamond dust moistened with oil, friction with which gives the necessary polish.

Having thus given a general shape to the stone, it remains to cut the surface into *facets*, some lozenge shaped and others triangular. In C these facets are in course of formation, and in D they are completed. The shape thus ultimately given to the cut diamond is known as the *brilliant*, and the parts of the stone below the culet and the girdle are distinguished as the *pavilions*, while the parts between the table and the girdle are sometimes termed *bezils*. In order to bring out the beauty of the diamond to greater advantage, it is necessary to preserve certain proportions between the several parts of the stone.

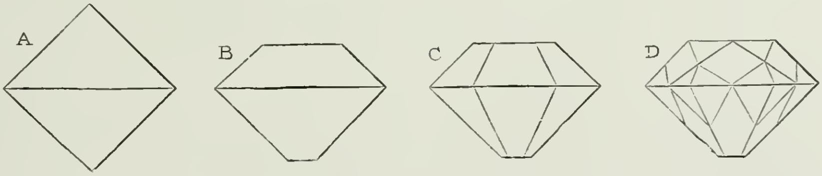


FIG. 10.—SUCCESSIVE STAGES IN CUTTING A BRILLIANT FROM AN OCTAHEDRON.

It is not every diamond that is adapted by its natural shape to be cut into the form of a brilliant: and stones which could not be so cut without great loss of weight are generally wrought into the form known as a *rose*. From Fig. 2 it will be seen that the rose has a flat base, and is domed above, the dome being cut into two rows of facets, the number of which varies, however, in different varieties of the rose.

After the diamond has been cut into the form of either rose or brilliant, it requires to be polished in order to develop that lustre and fire which form so prominent a feature in the beauty of the

diamond. To impart polish, the cut stone is embedded in a fusible metal, like solder, contained in a copper cup which is furnished with a wooden or metal handle. The diamond is fixed in the matrix by hand, and the soft metal when warm is worked into a conical form, having at its apex the exposed face of the diamond which is to be polished. When carefully mounted in this fashion, it is handed over to the polisher, who places the exposed face on a circular disc of iron mounted on a vertical axle, and rapidly rotating in a horizontal plane. The wheel is covered with diamond dust moistened with oil, and a number of diamonds may be placed on the same wheel at the same time. The polisher is represented at work in Fig. 9.

In cutting—or rather rubbing—the diamond into shape, and in polishing the cut stone, no abrading agent can be used except the diamond itself. It is this supreme hardness that gives much of the value to the diamond, for the roughest wear scarcely destroys the sharpness of the cut edges or deadens its polish. This exceptional hardness of the diamond is well known, and gives point to the expression "diamond cut diamond"; but the popular notion often credits this gem with an indomitable nature which it can scarcely claim. Among the many extravagant things which Pliny tells us is his remark that certain diamonds have such excessive hardness that when struck upon an iron anvil the hammer and anvil are torn asunder. Yet he coolly asserts that such stones can be subdued by digestion in goat's blood, provided that the curious solvent be fresh and warm! Without going to this height of extravagance, many believe, even nowadays, that a true diamond will resist the blow of a hammer. This popular error arises from confounding hardness with toughness—two physical properties which are entirely distinct. A piece of gutta-percha, for example, is so tough that it is torn asunder with difficulty, yet so soft that it may be indented by the finger-nail. On the other hand, the diamond is so hard that no other substance is capable

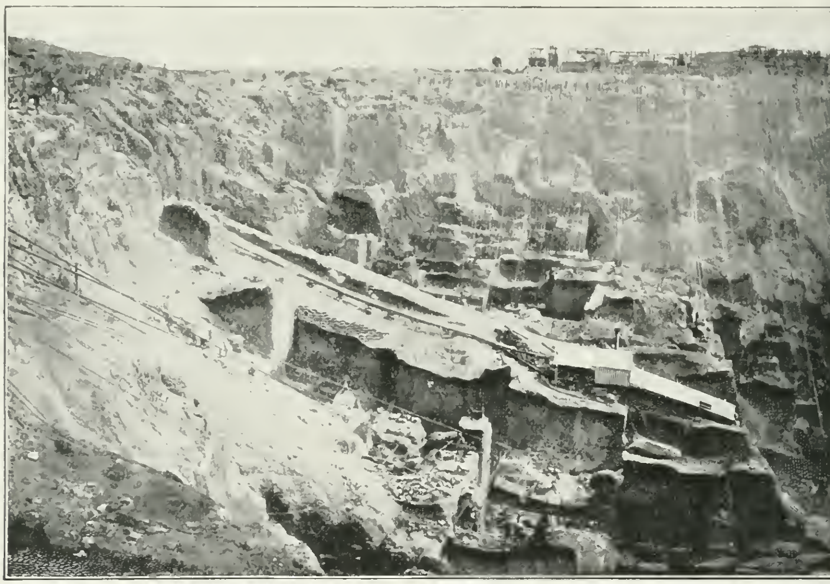


FIG. 11.—THE PUMPING ENGINE IN THE DE BEERS MINE, KIMBERLEY, SOUTH AFRICA.

of scratching it, yet so brittle that the Regent itself might be shattered into fragments by dropping it on to the ground from the height of only a few feet.

Everyone knows that the prime object in polishing a diamond is to develop its lustre with due effect. This remarkable lustre is the result of the high power which the stone possesses of reflecting, refracting, and dispersing — that is, of shedding forth, bending, and decomposing—the light which falls upon its surfaces. To attempt, however, a full explanation of the action of the diamond upon light would need a special article.

It was at one time believed that the diamond was incombustible, and there is little doubt that a great many beautiful gems have been destroyed in submitting them to the test of fire. In 1816 Sir Humphry Davy proved by careful experiment that the diamond was nothing but carbon in a pure and crystallised condition. The method by which a diamond can be burnt, and at the same time analysed, is indicated in the photograph (Fig. 12), and, although the experiment is a costly one, it is by no means difficult to perform.

Here is a glass vessel containing oxygen gas, and having at the bottom a small quantity of limpid lime-water. The diamond is placed in a spiral of fine platinum wire, or in a little boat of thin platinum foil, and a current of electricity from a battery is sent through the platinum. The metal offers a resistance to the passage of the electricity, and immediately becomes incandescent. This heat is then communicated to the diamond, and as soon as the gem is kindled the circuit is interrupted, and the platinum consequently ceases to glow. But the combustion of the diamond, once started, steadily continues; the carbon combines with the oxygen, forming carbonic acid gas, and the action is sufficiently energetic to maintain the diamond at a vivid glow. The combustion over, the lime-water may be shaken up, when it immediately becomes milky, in consequence of the formation of an insoluble carbonate of lime, which remains suspended in the turbid liquid.

FIG. 12.—BURNING A DIAMOND IN OXYGEN.

Placed in oxygen and fired by passing an electric spark a diamond can be burnt. This experiment proves that the beautiful stone is simply a form of carbon, because the only product of combustion is carbonic acid gas.

The student can convince himself in a cheaper way that a diamond is combustible by heating some diamond dust on platinum foil over a spirit lamp, and small diamonds may be burnt in the same way with the help of a blowpipe. But by performing the experiment in this way he misses the proof, afforded by the formation of carbon dioxide, that the brilliant diamond has the same composition as charcoal, a lump of which burnt under similar conditions would yield exactly the same product.

Before the discovery of the great mines

at Kimberley diamonds had been found only in rivers and alluvial deposits, which gave no clue whatever as to their origin. They had been washed down from some other place, but whence they came no man could say. But there is every reason to suppose that in the Kimberley mines the precious stone is seen for the first time in its matrix, and an examination of this rock may possibly give the key to the mystery of its formation.

The diamond mines at Kimberley, some of the features of which appear in Figs. 1, 11, 13, and 14, are the craters of extinct volcanoes. They cover several acres of ground, and have been worked to a depth of more than a thousand feet without any bottom having yet been found. Near the surface the earth or rock was found to be in a friable condition, and was yellow in colour. It was believed that when this upper layer was searched through the diamond area was exhausted, and many miners relinquished their claims when this stage was reached. But it is now discovered that the yellow rock represents only the surface of the mother rock, which is blue, the change of tint being brought about by weathering. It is this *blue ground*, as it is called, that is the true matrix of the diamond. It is of peculiar composition, and there is no doubt that it was forced up from below by volcanic action. It contains many minerals, and it is noteworthy that there are found in it pieces of black shale, and that shale forms one of the surrounding rocks. It has been suggested that we have in the presence of this material the source of the carbon from which the Kimberley diamonds come, and that the

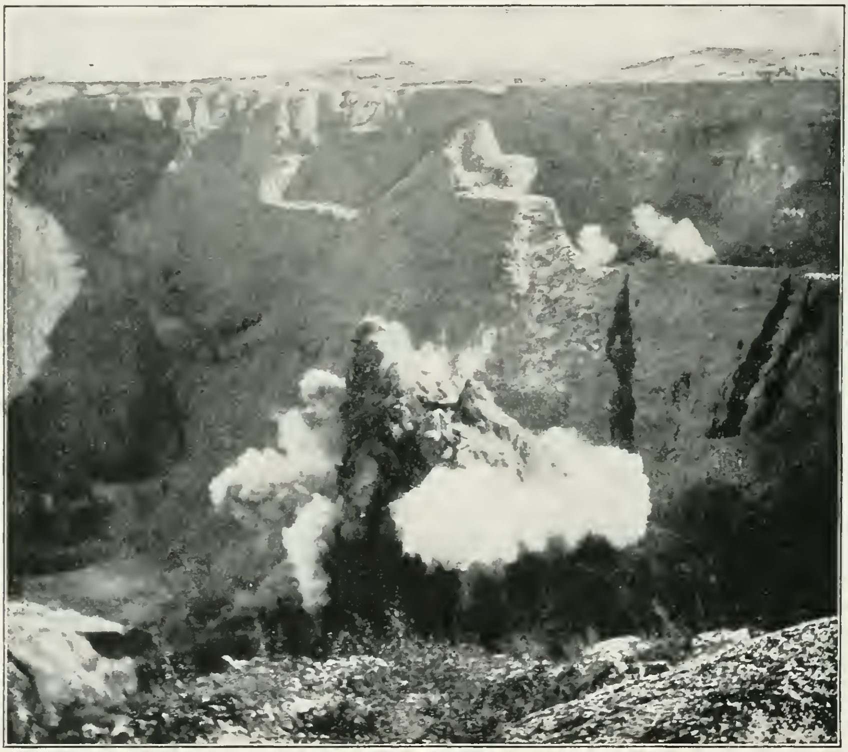


FIG. 13.—BLASTING OPERATIONS IN THE FAMOUS DE BEERS MINE: A SECOND AFTER FIRING THE CHARGE.

alteration from the *amorphous* to the *crystalline* form has been brought about by the agency of heat and pressure in the subterranean laboratory of Nature.

Now the question cannot fail to occur to the intelligent reader, "If such a change can be effected naturally, cannot the chemist in his laboratory imitate Nature and produce diamonds artificially?" The answer is in the affirmative. Diamonds have been produced by art, but of such small size—one measuring one-fiftieth of an inch across being considered an unusually fine specimen—that, to use a homely phrase, the game is not worth the candle. The experiment costs far more than the product is worth. As this achievement is one of the latest triumphs of modern chemistry, it will be interesting if we explain the general lines upon which experiments in diamond-making have been conducted.

Acting on the assumption that diamonds are formed in the earth by intense heat and great pressure, Mr. Hannay, of Glasgow, twenty years ago undertook some experiments which yielded noteworthy results. He enclosed within strong iron pipes certain carbonaceous substances, and submitted these closed retorts, as they may be fairly described, to the strong heat of a reverberatory furnace. Some exploded under the ordeal, but others withstood the treatment, and after a time were cooled down and sawn asunder. The carbon was found within in a compact coked mass, as might have been expected, and scattered about in its substance were some tiny crystals, microscopic in size, which were undoubtedly diamonds, but diamonds of no commercial value.

M. Moissan, the eminent French chemist who was the first to isolate the element *fluorine*, and who quite recently has been associated with Professor Dewar in submitting that element to the action of liquid hydrogen, was the next notable worker to try his hand at diamond-making, but he took up the matter in a more scientific manner. It must be remembered that the ordinary process of crystallisation presents no difficulty at all. Any crystallisable substance, such as nitre and sal-ammoniac, will throw out crystals when cooled from a saturated solution. But in carbon we have a substance which is insoluble in all liquids known. The strongest acid and the strongest alkali have no more effect upon it than water would have. But it has the curious property of combining with molten metals, and we know, as an example of this, that Bessemer steel is merely iron to which a definite amount of carbon has been added. Now it is quite easy to melt iron in the electric furnace, and if the metal during the process be packed all round with carbon it will saturate itself with that element. In other words, it will take up as much carbon as it can hold.

M. Moissan, having obtained in this way a crucible full of carbon-saturated iron, puts the vessel into a deep bath of molten lead, which causes the molten iron to collect in globules in the lead and to rise to the surface of the bath. At the same time the lead conducts the heat rapidly away, and causes each globule of iron to rapidly cool on its surface. But the interior of these balls of iron still remains in a molten condition, and that iron, containing an excess of carbon, expands as it solidifies, with the result that it is subjected to very great pressure. It now remains to examine the contents of these balls of metal, which have a diameter of only a few centimetres; and to do this first the lead in which they are imbedded and then the iron is dissolved away, the first-named metal with nitric and the second with hydrochloric acid. After this tedious process of dissolving away the metals has been gone through, there remains a residue of carbon, in which are

found diamonds with well defined crystalline faces, and which will answer to all the usual tests. But, as we have already intimated, these diamonds are, because of their minute size, only of nominal value.

It is noteworthy that the blue earth (*see* Coloured Plate), or *kimberlite*, as it has been christened by mineralogists, in which the diamonds are found is analogous in composition to certain meteorites. And in meteorites, diamonds, or something very nearly approaching them, have been found. Three of these "sky stones," which fell at Novo Urei (South-Eastern Russia) in 1886, were submitted to analysis, and the results were laid before the French Academy of Sciences. Carbon, in the form of carbonado, or black diamond, which is extensively used for rock drilling, was found in these stones to the extent of 1 per cent.

Quite recently news came from America that a veritable diamond, which was described as being as perfect in form as any afforded by the Kimberley mines, had been found in a meteorite which had been discovered in Arizona, and that this diamond had been placed in the Museum of Natural History at New York. It is curious to find that the little rhyme so familiar to our childhood's days, in which a star is compared to "a diamond in the sky," should have a scientific significance.

FIG. 14.—IN THE DE BEERS MINES: A TIMBERED TUNNEL AT THE 1,000 FEET LEVEL.

THE LIFETIME OF A SEED.

BY ALEXANDER S. GALT.

IF space permitted, a most interesting chapter could be written upon that part of the seed's existence which is passed within the sheltering envelope or fruit. We should see how, out of a mass of dividing cells, each filled with the all-important protoplasm, the various parts of the seed are built up, how the tiny embryo is formed, and how in many cases food to supply the infantile wants of the little seedling is stored up in cells around it ready for use when required. It is as if a provident mother started her offspring with a certain amount of invested capital before sending it on its journey into "a far country." We should notice how many and diverse are the methods by which the parent plant gets rid of its ripe seed, and, as far as possible secures its wide dispersal. Some seeds, furnished with appendages, like the thistle-down, are so light that a gentle breeze will carry them far from the point whence they originated. In others the flight is heavier, and sooner over, as in the winged seeds of the plane, elm, and sycamore. Others, which have no wings, are carried by birds and animals. Thus the succulent fruits of the ivy are plucked and eaten by birds perhaps a mile or more from the parent bush, and the horny seeds there rejected. Nature has many resources in securing seed dispersal, but we must not dwell upon them here. We have to consider one phase only of the question, and that is, "How long will the seed live ?"

FIG. 1.—GENUINE "MUMMY WHEAT" AT THE BRITISH MUSEUM.

We know quite well that if the seed secures a resting place in the earth it will, in course of time, produce a plant, provided that it be a plump, well matured specimen, and that conditions are favourable to growth. We will suppose that a seed, say, of wheat, has been furnished by nature with everything needed to make a plant, or, in the words so frequently heard, has "good germinating power." We see at once that two contingencies may arise: (1) The seed may never reach the ground at all; or (2) the circumstances may be such that growth is impossible. The point we have now to consider is, therefore, "How long can the seed remain

in this prison of prevention, and yet preserve its germinating powers?"

Perhaps there has been no subject connected with the absorbing study of plant life over which so much ink has been shed. All sorts of instances have been brought forward in which it has been declared that seeds have maintained their vitality for hundreds, nay, thousands, of years. The "mummy wheat" is perhaps the most familiar instance of its kind. Those of my readers who have visited the Egyptian section in the British Museum—that great international repository of science—have probably seen some of the blackened grains that have been recovered with various mummies—grains of wheat that take us back to the days of Rameses the Great and Meneptah, when royal Egypt was a power in the world. "Can these dry things live?" we may well ask. Here they are, blackened with age (Fig. 1), with all the weight of their thousands of years upon them. It has been claimed that they will grow, as if the thousands of years had been but a day. The so-called "mummy pea" is in the same case. Now it is impossible to doubt the authenticity of some of the testimony which declares that "mummy wheat" will grow, but the

FIG. 2.—ARABS SELLING "MUMMY WHEAT" TO TOURISTS IN CAIRO.

scientific doubter wishes not only to be assured of this, but also of the *age* of the wheat. The truth is that the Arabs and fellaheen of Egypt have found out that the Westerner has gold to part with in return for wheat, provided the latter has, at any rate, the semblance of age, and they have set their wits to work to produce a modern antique article which will pass muster. By some method, known only to themselves, they have produced upon new wheat the outward blackening of the skin which stamps the thing as the genuine "mummy" article—in the average buyer's eyes (Fig. 2). This wheat will grow. There is no reason why it should not, for the embryo has been left unhurt by the "treatment." Now we begin to see daylight; a new factor has been introduced, and we see that it considerably affects the results. We may make up our minds straight away that wheat hundreds of years old will not grow. The whimsical statement made in one quarter that, after sowing a crop of "mummy *wheat*," "mummy *peas*" were obtained is just as likely to be true as that the grain of the Pharaohs should sprout in the twentieth century. Presently we shall see why the thing is an impossibility. Cases of supposed retained vitality may be obtained in the raspberry seeds unearthed in a British tumulus in Devonshire, found, so the story goes, side by side with coins of the Emperor Hadrian; and of the seeds of bird's-foot trefoil (*Lotus corniculatus*) found in Roman tombs dating back to the second century. There is little doubt that the seeds were discovered in these interesting surroundings, but it would be difficult to prove that they had been there all the time. We know quite well that raspberry and bird's-foot trefoil seeds nowadays will not retain their vitality in this way. The obvious inference is, therefore, that they were only moderns, after all, and the case breaks down at once.

We come now to that section in which strange plants make their appearance in certain situations as the result of digging operations in which previously buried soil is brought to the light. Certain plants, new to the neighbourhood, take possession of this newly exposed soil, and the popular mind, constrained to find some sort of reason for the occurrence, declares that the seed was in the soil all

FIG. 3.—THE COLTSFOOT (*TUSSILAGO FARFARA*).

This British wilding is both pretty and plentiful. Its bright yellow flowers appear in spring before the leaves. The plant will grow almost anywhere, and seeds so plentifully that it soon takes possession of all waste places.

the time, that it was buried so deeply that it could not grow before, and that it had thus been buried for many, many years, because that particular spot has never been deeply dug before. Several authentic instances have been given of Coltsfoot, *Tussilago Farfara* (Fig. 3) behaving in this way. In America it has been noticed that after a forest fire the vegetation that follows is unlike the previous one; but if we were to argue from this that the seeds had been lying dormant in the soil, and had survived both the incarceration and the roasting,

we should be following dangerous paths. After the Great Fire of London in 1666 the yellow rocket appeared in considerable profusion over the flame-swept area, and

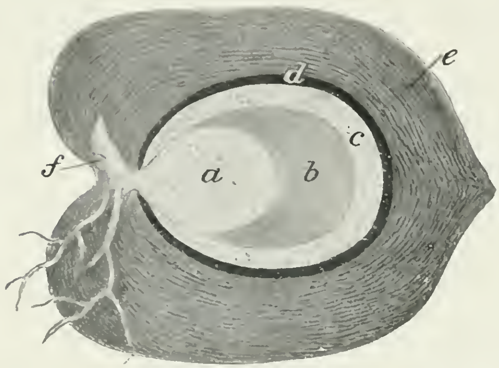


FIG. 4.—SECTION THROUGH A COCOANUT SHOWING THE VARIOUS PARTS OF THE FRUIT.

e, husk surrounding nut; d, "testa," which is very hard and bony; c, fleshy "mesocarp," the white eatable matter; a and f, the growing embryo; b, hollow portion.

it had not been known in the locality previously. An even more recent occurrence is that of a strange horned poppy at the silver mines at Laurium, in Greece. In this case the soil in which the poppy seed was supposed to have lain was buried ten feet deep beneath cinder and slag thrown out by the workmen some 1,500 or 2,000 years ago.

Now let us see how far the physiological botanist can give us light upon the matter. In the first place, it must be borne in mind that, as long as the seed is alive, the embryo within it must breathe. Oxygen is taken in, and carbonic acid gas given off. We know that respiration is a destructive process.* In the seed it can only be conducted at *the expense of the reserve store of nutriment*, which the embryo depends upon to support it during germination. Continuous respiration means therefore continual wastage of the stored food (*see* Fig 8 *e*). To use a homely simile, the embryo is living upon its *capital*, and with the seed, as with a man, the end is then well in sight. After a time the "capital" of the embryo is so exhausted that there is not sufficient to support germination, and the result is that the seed cannot grow, any more than the man can subsist without means. True, it may be said that respiration is reduced to a very low ebb in the dried seed. So it is; but, reduced or not, it goes on as long as the embryo is alive. We may sum the matter up by saying that *respiration* means *wastage*, continued wastage means *exhaustion*, and exhaustion *death*.

* *See* "A Fallen Leaf," CASSELL'S POPULAR SCIENCE, Vol II., p. 290.

So far we have only proved that the seed must die after a time. Now we have to decide what that time is, and this is a more difficult question. The character of the *testa*, or skin (Figs. 4, 8, and 9) largely governs the length of life of the seed. Thus, where the "testa" is very hard, as in the case of the cocoanut (Fig. 4). a long life is ensured. *Ceratonia*

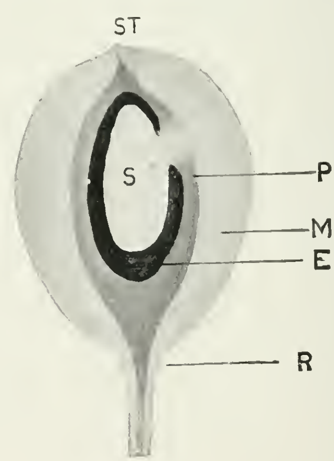


FIG. 5.—THE PARTS OF A PLUM AS SHOWN IN SECTION.

S, kernel, the true seed; E, stone ("endocarp"): M, "mesocarp," or succulent layer; ST, skin ("epicarp"); R, stalk.

Siliqua, the locust (Fig. 6), has very hard seeds, and an authentic case is on record that after forty-nine years one seed only, out of a handful, germinated. Even then the seedling was so weak that it soon withered away, so that practically there

was total failure. This, too, was after only forty-nine years, and with a seed whose testa is much harder than that of wheat. To take an instance where the life is very short, and, moreover, rests upon a very precarious basis, we have the willow, whose seeds require to be sown at once if the best results are expected. Once let them get dry, and death results, and even if they are kept for only two or three weeks life is reduced to the point of extinction. The seeds of the poppy are also very short-lived, and frequently two-year-old seeds will fail to grow. As a rule, a grain of wheat will not germinate after the seventh or eighth year. In making experiments of this kind we have all our facts before us, and particularly we *know* the age of the seed.

FIG. 6.—THE LOCUST *(CERATONIA SILIQUA).*
The seeds of this tree have a hard skin and live to a great age.

If the statement concerning the gradual wastage of reserve material as the result of respiration is correct, we should expect that each year the seed is kept out of the ground would see a corresponding diminution in the vigour of the seedling that could be produced. This also is well borne out by facts. All things being equal, the younger the seed the stronger the seedling. It is a matter of common gardening knowledge that melon and cucumber seeds in their second year produce less vigorous plants than do those in their first year. As this less vigorous growth is accompanied by an increased tendency to fruitfulness, the fact is taken advantage of by the cultivator. Speaking generally, it is found that a "starving" process has the effect of reducing the vigour of growth, whilst increasing fruit-bearing proclivities. In stocks, too, more double flowers are borne by plants resulting from old seed than from new.

Naturally, the conditions of storage affect the longevity of the seed to a marked degree, but for practical purposes, the following list of a few common seeds shows the length of time beyond which it is not advisable to keep them. This does not mean that they would not grow at a later period, but only that they would produce such weak plants that they would be useless for practical purposes.

Rye ... ... Sainfoin ... ... Maize	1 to 2 years.
Wheat ... ... Oats	2 years.
Turnip ... ... Cabbage ... ... Mustard	3 to 4 years.
Peas ... ... Beans	4 years.

If, now, we take these facts, and apply the lesson they teach us to the pretty stories of the "mummy wheat" and "mummy pea," we can only come to the conclusion that a mistake has been made in the *age* of the seed that has germinated, and we have seen how Arab trickery has made

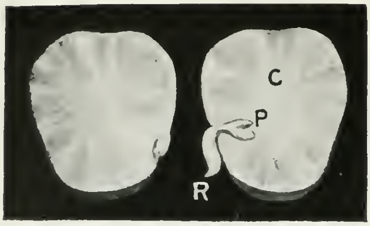


FIG. 7.—A GERMINATING BEAN.

R, radicle, which is to become the root; P, plumule, a bud which develops into the stem. Each half of the bean, C, is a cotyledon or seed leaf. The embryo in this case fills the whole of the seed.

this possible. If, instead of the few grains that an ancient religion decreed should be placed with the dead, the whole of the mummy cases had been filled with wheat, it would scarcely have sufficed to supply the quantities that have been distributed of late years. The curiosity of strange plants springing up on newly turned up soil is also open to an easy explanation. Since the growth of a plant or collection of plants is governed by the presence or absence of suitable conditions, it may be that the character of the newly turned up soil has been such that only a certain subject can grow in it. It has been mentioned that the coltsfoot is notorious in this respect. We remember that its seed is light, and easily carried by wind, and that it will grow in a heavy, cold medium, where other and more particular plants would fail. We have only to keep our eyes open to be assured of the fact that a mound of freshly turned up earth, no matter what its consistency, is almost sure to be first taken possession of by coltsfoot. Nature's methods of distribution are so subtle and well adjusted that we take but little notice of them, and the results sometimes seem to savour of the miraculous when we have not been able to follow the working of the causes that have led up to them.

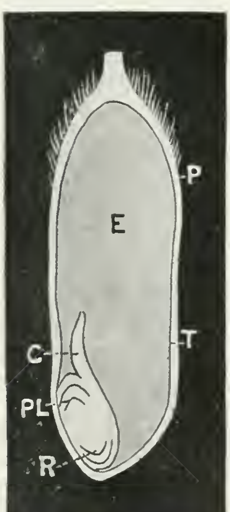


FIG. 8—WHEAT SEED IN SECTION.

C, cotyledon (one only); PL, plumule; R, radicle, or future root; these three constitute the embryo. The endosperm, E, represents the stored-up nourishment. T is the testa or skin.

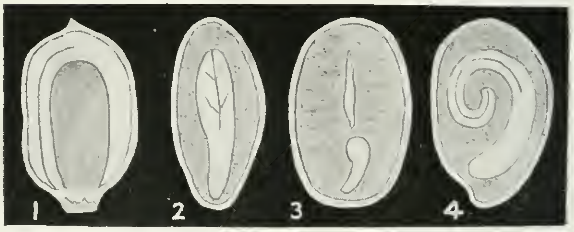


FIG. 9.—THE EMBRYO DIFFERS CONSIDERABLY IN SHAPE AND DISPOSITION.

1, Marvel of Peru; 2, Barberry; 3, Pæony; 4, Potato.

In addition to a supply of air, moisture and a certain amount of heat, varying from 40° F. to 90° F., are necessary for germination. Prolonged exposure to either a high or a low temperature is fatal; but, on the other hand, it has been proved to demonstration of late years that seeds can bear very low temperatures, under certain conditions, with impunity. It seems that we must, after all, reconsider the possible effect of extremes of cold upon the vitality of seeds. Arctic voyagers long ago pointed out that seeds of Arctic plants must, for a considerable portion of the year, be subjected to great extremes of cold. Yet they grow. The effect of the snow blanket was, of course, held to account in a great measure for this. Then came the experiments inaugurated by Professor Dewar in 1899, with the assistance of Sir William Thiselton-Dyer, in which the seeds of wheat, barley, peas, mustard, vegetable marrow, and musk were subjected to

the temperature of liquid hydrogen (—252° C.).*

These seeds were enclosed in a sealed glass tube, cooled in liquid air,† and then transferred to the hydrogen in which they remained for an hour. Seeds of musk were also *soaked in liquid hydrogen for six hours.* It was feared that a rupture of the tissues would be the result, but nothing transpired. The seeds were sown, and most of them grew. *There was no difference observable either in the condition of the seeds themselves or of the plants resulting from them.* Yet these seeds had been subjected to the fearful temperature of 453° F. below that of melting ice, or the temperature that they would have experienced in *moving through space.* Side by side with this is the fact that protoplasm is coagulated—that is to say, killed, as far as we understand the word—by exposure to a temperature of 75° C. How far the thermal opacity of the seed coats protected the embryos we do not yet know. We must wait for other experiments to demonstrate this; but, as Sir W. Thiselton-Dyer points out, it is possible for two substances at very different temperatures to remain in juxtaposition for some time, and for each to retain its own temperature, as in the case of liquid air contained in a silver vessel heated to redness, the *difference in temperature being* 1,000° *C.* "Were the embryos really frozen?" is the query that now comes naturally, and for the time being there is no answer to the question, except the one in the affirmative. It would seem as if they *must have been* frozen, and yet we should expect that so extreme a degree of cold would have killed all semblance of life.

* *See* "Proceedings" of the Royal Society, Vol. LXV., p. 161; also the pamphlet "On the Influence of the Temperature of Liquid Hydrogen on the Germinative Power of Seeds," by Sir William Thiselton-Dyer, K.C.M.G., C.I.E., F.R.S.

† *See* CASSELL'S POPULAR SCIENCE, Vol. I., p. 225.

FIG. 10.—THE GARDEN PEA *(PISUM SATIVUM).*

The "mummy pea" (P. umbellatum or elatius) has flattened stems, and produces its flowers in clusters at the tops of the stems.

THE SUN: OUR FIRE, LIGHT AND LIFE.

WE considered the sun as ruler of the solar system before regarding him as the source of nearly all the light and heat received by that system, because the study of the heavenly bodies and their movements leads us first to recognise the sun's power as a ruler. It is in this power, in fact, that we find the explanation of motions which otherwise could not possibly be understood. It is only because the sun's mass, and his consequent might, have been fully recognised, that the system of modern astronomy is regarded as established. So far as the mere movements of the planets are concerned, the theory of Tycho Brahe would have as good a right to our acceptance in these times as that of Copernicus. But when once we perceive that these movements are ruled, and that mass or quantity of matter measures the ruling power, we see in the sun the chief ruling body.

The brightness of the sun's surface is so great that it is no easy matter to express it in terms of terrestrial sources of light. In a celebrated experiment, conducted by Professor Langley at Pittsburg in 1878, it was found that the sun came out as radiating, area for area, eighty-seven times as much heat and 5,300 times as much light as the white-hot metal in a Bessemer converter after the air-blast had been continued some twenty minutes; yet the glowing steel was so brilliant that white-hot iron, as it was poured into the crucible, showed deep brown by comparison, like black coffee poured into a white porcelain cup. Yet this experiment was made under conditions very distinctly unfavourable to the sun, the light of which had to pass through the smoke-laden atmosphere of Pittsburg before it could be tested for the experiment.

The figures which have been deduced in order to express the light of the sun in terms of terrestrial lights are quite beyond any power of ours to realise. A white surface has been illuminated by the sun when overhead and compared with the illumination given to it by a standard candle at a metre distance. The sun came out as fully 70,000 times the more effective. If this number 70,000 be multiplied by the square of the sun's distance expressed in metres, we get 1,575 *billions of billions of standard candles* as representing the light emanating from the disc of the sun as we see it, and *four times that number* for the radiation from his entire surface.

Even this vast number by no means expresses the actual total light radiation of the sun. For it has undergone loss in two ways before it has reached us and we are able to measure it. This loss is partly due to absorption in our atmosphere. At the sea-level, with the sun overhead and a pure air, this atmospheric absorption amounts to about 40 per cent., so that at best only about three-fifths of the sun's light actually reach us. But there is also a serious amount of absorption which takes place within the atmosphere of the sun itself, and it would appear that, could this envelope be removed, the amount of light received by us from the sun would be about doubled.

Comparing the sun as we see him with other celestial bodies, he has been ranked as 600,000 times as bright as the moon, 7,000 million times as bright as Sirius, and about 100,000 million times as bright as the average first magnitude star.

The determination of the sun's heat

and of his effective temperature is of even more interest than his light. The amount of heat required to raise the temperature of one kilogramme of water 1° C. is termed a *calorie* and is taken as the unit of heat measurement. If, then, we expose a given quantity of water for a given time to the heat of the sun, and measure the rise in temperature, we have the means for expressing the solar radiation in terms of the heat unit. The earliest values for the *solar constant*, as it is called, were about 17 or 18. Later determinations have continually raised this figure, and we are now compelled to estimate the *solar constant* as at least 30 and, quite possibly, 40 calories.

If we express this output of heat in terms of its power to melt ice, then taking the *solar constant* at 30, since it requires 79¼ calories to melt a kilogramme of ice, if this kilogramme form a sheet one square metre in area, it will have a thickness of about $1\frac{1}{12}$ millimetres, and it will be melted in about 2 min. 38½ sec., or 1 millimetre in 2 min. 26 sec. This will be very nearly at the rate of one inch per hour, so that the heat received by the earth from the sun in the course of an entire year would be sufficient, if equally distributed over the whole surface, to melt a mass of ice 180 feet in thickness.

This is the sun's heat as it reaches us. If we desire to know the amount of heat emitted by a given area of the sun's surface—one square metre, for example—then we must multiply the above figures by the square of the sun's distance and divide by the square of its radius. The sun's distance is 215 times its radius, and the square of this quantity is 46.200. This, then, is the proportion which the heat emitted by a square metre of the sun's surface bears to the heat received by the same area of the earth's surface. Instead, therefore, of melting one inch thickness of ice every hour, it would melt more than 64 feet every minute. Professor Young sums up the matter by supposing a bridge of ice 2¼ miles square in section and reaching from the earth to the sun. If the entire heat of the sun could be concentrated upon this vast mass, it would be melted in one second of time, and in seven seconds more would be converted into vapour.

When we turn to the question of the temperature of the sun, we are necessarily obliged to confine our inquiry to the question of the temperature of its radiating surface. Assuming that that surface radiates as freely as lampblack—the best radiator we know—Mr. W. E. Wilson finds the "effective temperature" as 6.590° C., a result with which several other careful determinations are in close accord.

One horse-power is equivalent to between 10 and 11 calories of heat per minute. It follows, therefore, if we take the *solar constant* as 30 calories, that the energy received by every metre of the earth's surface exposed to a vertical sun is very nearly equivalent to an engine of 3 horse-power working continuously. This, in the course of a year, would be equivalent to the raising of nearly 1,000 tons a mile high per metre.

It is a singular circumstance, by the way, that of all the tremendous work implied by the emission of solar heat, only a very small portion seems utilised. The earth captures only one in 2.128 millions of the solar rays. All the planets together capture about 1 in 234 millions. The rest—that is, 234 millions of rays for every one which falls on a planet—pass into the star-strewn depths. They may reach planets travelling round other stars, just as the rays of Sirius and Vega, Arcturus, Capella, and Aldebaran, reach our earth. But it is as difficult to perceive how their energies can be thus utilised, as to understand how such trifling supplies of heat as we receive from the stars can produce any effects corresponding to the

enormous amount of seemingly wasted energy which they represent.

We must now study the physical condition of the orb which is thus the fire and light, and therefore in effect the life, of the solar system. We have here a subject which has grown marvellously in interest during the last fifty years. In fact, it may almost be said that the study of the sun's physical condition by other methods than mere telescopic observation was not even commenced before the nineteenth century.

FIG. 1.—SUN'S CORONA AS SEEN AUGUST 9TH, 1896, AND DRAWN BY M. HANSKY FROM HIS PHOTOGRAPHS.

We have first to consider the results of the investigation of the sun's light with the spectroscope. The optical relations involved in this investigation, and to some degree the physical relations also, belong to other departments of science than astronomy, and have been dealt with elsewhere. Here it is only necessary to state the laws which are to guide us in the interpretation of the various results of spectroscopic inquiry into the condition of the heavenly bodies.

We find that when the light from a solid or liquid body white with intensity of heat is caused to pass through one or more triangular prisms of glass, the white light is spread into a rainbow-tinted streak or spectrum, the different colours whose mixture forms the white light being bent in different degrees by the action of the prism or prisms, so that they travel in different directions as they leave the last prism. The red rays are least bent, the orange next, the yellow next ; then, in order, the green, blue, indigo, and finally

the violet. And when care is taken—by allowing the light to shine only through a fine slit—to cause the several tints of each colour of the rainbow to travel clear of neighbouring tints, it is still found that a perfect rainbow-tinted streak is produced, the red merging into the orange, by insensible gradations, the orange into the yellow, and so forth. In other words, no tints are wanting in the light of glowing solid or liquid matter, wherefore its spectrum is a perfect, or (as it is technically called), a continuous, rainbow-tinted streak.

But the light of the sun, when analysed in the same way, is found not to contain all the tints of the rainbow. Newton, indeed, in his original experiments on the sun's light, obtained the result just described as happening in the case of glowing solid or liquid matter, but that was because he did not sift the light finely enough. Wollaston first, and later (and much more completely) Fraunhofer, making the slit through which they examined sunlight very narrow, found first that a few, and afterwards that many, tints are missing from sunlight. Fig. 2 is a picture of the solar spectrum (uncoloured, but the colours are indicated verbally below it), with the chief dark lines (or missing tints) noted by Fraunhofer. But to understand the nature of his work the intermediate finer dark lines must be described: A and B are strongly marked lines near the red end of the spectrum; *a* is a band of several lines between them; C is a dark and strong line. Between B and C Fraunhofer counted nine fine lines: between C and D about 30—D is a double line in the orange-yellow. Between D and E Fraunhofer counted 84 lines—E is a band of several lines in the green, the middle line stronger than the rest. At *b*, also in the green, are three strong lines, the two farthest from E being close together. Between E and *b* Fraunhofer counted 24 lines; and between *b* and F more than 50. F and G in the blue are strong lines. Between F and G Fraunhofer counted 185 lines; whilst two very broad dark lines, now known as H and K, stand at the very end of the spectrum, where

> "The last gleanings of refracted light
> Die in the fainting violet away."

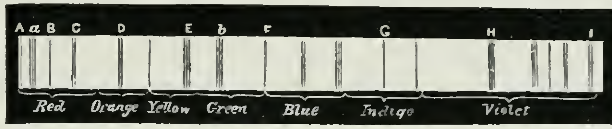


FIG. 2.—FRAUNHOFER LINES IN THE SOLAR SPECTRUM

It is necessary to describe Fraunhofer's map of the spectrum thus fully because his lines are constantly referred to in describing spectroscopic researches, and his inquiries supplied in reality the basis of the modern science of spectroscopic analysis. It must be understood, however, that modern observations reveal a far greater number of lines than Fraunhofer saw. In fact, it may truly be said that, while in sunlight there are all the colours of the rainbow, yet thousands of tints are missing from the red, thousands from the orange, and, in fine, tens of thousands from the spectrum as a whole.

Now, the interpretation which science has found for these missing tints is that they show the action of the vapours of certain elements in absorbing light emitted by the sun. It is found that every substance, when in the vaporous form, and glowing with intensity of heat, shines with certain tints only. Its light, dealt with by the spectroscope, does not form a rainbow-tinted streak, but simply produces a certain number of coloured images of the slit through which the light is received. One substance—sodium—shows only a strong double orange-yellow line, and a few faint lines belonging to other parts of the spectrum. Hydrogen shows four bright lines—one red, one

greenish-blue, one deep blue, one violet. Iron shows at least 2,000 lines of all the colours of the rainbow, but still they represent only 2,000 tints among the infinity of tints forming the rainbow-tinted spectrum. But it was also found that a vapour has the power of absorbing the same tints which it emits. If a mass of glowing solid or liquid matter is shining through a mass of glowing vapour, and the spectrum of both is examined, we find that the rainbow-tinted streak from the solid or liquid is crossed by dark or bright bands corresponding to the tints of the vapour. The lines are dark if the vapour is cooler than the solid (and so absorbs more of its own special rays than it emits), and bright if the vapour is hotter than the solid (and so emits more rays than it absorbs). If both substances are at the same heat, we have a rainbow-tinted spectrum without either dark lines or bright lines ; in other words, we find in this case no evidence in the spectrum to show that the light from the glowing solid or liquid body has passed through the glowing vapour. In point of fact, we may say that in such an experiment the tints belonging to the vapour's spectrum are just as strong as though the glowing solid or liquid were not present at all ; so that they appear (1) as dark lines, (2) as bright lines, or (3) are lost in the rainbow-tinted background, according as (1) they are fainter or (2) stronger than that background, or (3) of the same lustre.

We see, then, that the dark lines in the sun's spectrum indicate the presence of vapours around the sun which are cooler than the sun's mass. If any bright lines should be made out, they would indicate the presence of vapours hotter than the general mass. And lastly, many vapours may exist of whose presence we can obtain no spectroscopic evidence, simply because they are at the same temperature as the general mass of the sun.

Studying the dark lines in this way, it has been found that hydrogen, sodium, barium, magnesium, calcium, aluminium, iron, manganese, chromium, cobalt, nickel, zinc, copper, titanium, carbon, silicon, and other elements exist in the sun's atmosphere, and are nearly always cooler than the sun's surface. Occasionally the lines of hydrogen are seen bright when certain parts of the sun are examined, showing that at such times the hydrogen there is hotter than the surface underneath it.

Above the surface of the sun, then, there is a region, filled with intensely glowing gases, many of them the gases of metals permanently solid here on earth. But of what is that bright surface itself composed? The general opinion is that the *photosphere*, as the luminous surface of the sun is generally called, is a sheet of luminous cloud ; that intensely heated gases rushing upward from the interior of the sun with great velocity, and expanding rapidly as they rise (for both temperature and pressure must diminish towards the exterior), are condensed into a cloud-like form. Since carbon is the most refractory element of which we have experience here, it has been supposed that carbon is the chief constituent of these photospheric clouds, which no doubt make up the rice-grains and granules described in a former paper. Such condensation clouds would be much more luminous than the gases out of which they were formed and amongst which they floated.

We owe much of our knowledge of the sun to what is evidently a purely accidental relation—namely, that the apparent diameter of the moon is almost exactly the same as that of the sun. Both discs vary according to the varying distances of the two bodies. The average lunar disc is rather less than the average disc of the sun. But when the moon is at her nearest she looks larger than the sun even at his nearest, and considerably larger than the sun when he is farthest from the earth. Let it suffice here to

KANGAROOS, MALE AND FEMALE.

THE FEMALE KANGAROO IS OF A BLUE COLOUR, WHILST THE MALE IS RED-BROWN. THESE CURIOUS MARSUPIALS AFFORD AN EXCELLENT ILLUSTRATION OF THE LAW THAT "THE MALES OF A GIVEN SPECIES ARE DARKER THAN THE FEMALES."

note that, whereas usually, when new, the moon passes above or below the sun, she sometimes passes athwart his disc. If, when this happens, the moon is near enough to us, her disc will entirely hide the sun's face for a short time (not exceeding eight minutes under any circumstances). Thus, for a while we see the regions outside the sun's globe without being dazzled by his own splendour. Moreover, our own air towards the sun's place in the sky is for a while in darkness. We can then tell whether close by the sun any matter exists which is usually veiled from view both by his own light and that of the sunlit air.

The first and most striking circumstance noted on such occasions is the existence of a glory of light all round the sun, or rather round the black disc of the moon. But ordinary vision discovered nothing worth noting about this glory until long after the telescope had been applied to examine details round the eclipsed sun. So we may consider here what the telescope has shown, without passing from the actual order of discovery, and with the advantage of considering the parts of the sun outside his globe in the order of distance from his surface.

First, then, the telescope showed quite close to the black body of the moon a number of red objects. They were compared by some who saw them in 1842 to garnets round a brooch of jet. They were then called the red prominences, and have since retained the name, and they rose from a shallow layer of material of the same colour, which we now know as the *chromosphere*, and which covers the sun pretty uniformly to a depth of about 3,000 miles.

The eclipse of 1851 (July 28th) made it clear that these prominences belonged to the sun and not the moon. The total eclipse of 1868 (August 18th) showed that they gave a spectrum of bright lines, indicating that they were composed of glowing gas, and one of the observers of that eclipse, M. Janssen, found that they were bright enough to be seen in his spectroscope after the eclipse was over. Before the news of this observation reached England, Mr. (now Sir) Norman Lockyer had succeeded in observing the prominence lines without an eclipse at all. The gases, indicated by these lines were those of hydrogen and helium, the latter an element not recognised as a terrestrial constituent until Professor Ramsay discovered it in the Norwegian mineral cleveite in the year 1895.

From the time of Janssen's and Lockyer's discovery the study of the spectra of prominences and of the chromosphere has been followed at several observatories, particularly in Italy. Huggins soon showed that by using great dispersive power and a wide slit it was possible to see, not only the spectrum of a prominence, but its actual form. It has been found that, like the spots and faculæ, the prominences vary in number and size from time to time, and that they do this conjointly with them. Prominences are of two chief classes: hydrogen prominences, which, like the faculæ, are found in almost all latitudes and consist principally of hydrogen, calcium, and helium; and "metallic eruptions," which are much more closely associated with spots and show the lines of sodium, magnesium, titanium, iron, and other metals.

The changes in form and size which prominences often undergo are most remarkable. The accompanying figures, representing a prominence observed by Dr. Fenyi at the Kalocsa Observatory show a by no means exceptional activity. At 7 h. 10 m. the prominence extended along the sun's limb for about 12°, and was some 60″, or 27,000 miles, in height. Half an hour later it had entirely changed its form. Of the five or six roots rising from the chromosphere only the central one remained, though the branches spread out

in both directions about as far as before. By seven minutes past eight the more southern branch had shot up to a height of 63,000 miles; at half-past eight the southern branch had almost disappeared, and the northern formed a mighty streamer 114,000 miles in length. A quarter of an hour later the streamer was about 100,000 miles high, and by 9.35 the prominence had practically disappeared, except for a low bank (Fig. 3).

Far more violent was another storm watched by the same observer on September 19th, 1893. An enormous column of hydrogen was seen 166,000 miles in height. A violent up-rush at the rate of 123 miles a second set in, carrying the topmost flames to a height of 224,000 miles, the whole disappearing a minute and a half later.

The lines of hydrogen and the two great lines in the violet, H and K (due to calcium), are frequently seen *reversed*—that is to say, bright, as they are in prominences upon the disc of the sun itself.

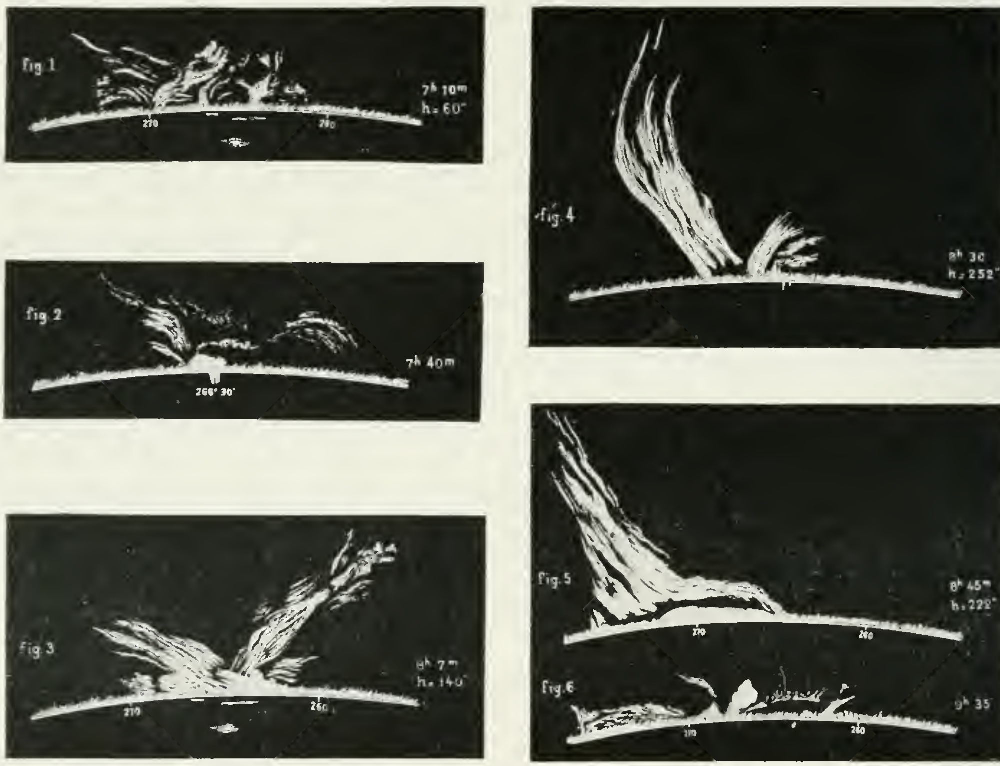


FIG. 3.—RAPID CHANGES IN A "PROMINENCE," OBSERVED BY DR. J. FENYI AT THE KALOCSA OBSERVATORY.

The time at which the observation was made may be seen upon each Figure.

(Reproduced from the Memoirs of the Society of Italian Spectroscopists.)

This takes place in the spectrum of faculæ, which show these lines as both bright and dark at the same time, the bright line being a very narrow line in the centre of the much broader dark absorption line (Fig. 4). So, too, again, these lines of hydrogen and calcium, and sometimes others, are seen bright in the spectra of spots.

The frequency with which the H and K lines of calcium are reversed, and their

extreme breadth and darkness in the ordinary solar spectrum, has led to an ingenious method of photographing the sun in monochromatic light. The principle employed is to pass the light of the sun through a complete spectroscope furnished with a slit at each end. The second slit, which is placed in the plane where the spectrum is formed, is so adjusted that only the light corresponding to one particular ray of the spectrum—generally the K line—is allowed to pass through it. By one device or another the first slit is made to pass across the disc of the sun, whilst the second traverses a photographic plate. The only light, therefore, which falls upon the plate is derived from regions where the K line is bright—that is to say, where there are bright calcium prominences present on the sun's disc. Such an instrument, known as the *spectro-heliograph*, was first devised in America by Hale and in England by Evershed, and affords a ready means of photographing the whole of the chromosphere and prominences (Figs. 5 and 6).

Eclipses, therefore, are no longer needed for the study of the chromosphere and prominences. But there are two regions of the sun's surroundings which can only be examined during a total eclipse; the one of these lies close to the sun's surface, and is much lower than the chromosphere; the other stretches away from the sun much further than the loftiest prominence.

The first of these is the region of what is known as the "Flash." It is so called because, if the spectrum of the sun is watched during an eclipse, there comes a moment when the dark body of the moon has just entirely hid the whole disc of the sun and totality begins. Up to this moment the usual solar spectrum of the dark Fraunhofer lines on a bright background has been seen. At that moment this Fraunhofer spectrum disappears, and its place is taken for an instant by thousands of bright lines. These are hidden in about a couple of seconds by the further progress of the dark moon, and their momentary appearance const tutes the "Flash." It was first seen by Young in the eclipse of 1870 (December 22nd). It was photographed by Shackleton in that of 1896 (August 9th), and has since been photographed in all the eclipses which have followed. The depth o this stratum is about 800 miles, and it constitutes almost the lowest region of the sun's atmosphere which we can study. The conclusion of most astronomers is that the region of the Flash represents as nearly as we can get to it, the *reversing layer*—that is to say, the region where these glowing gases are situated which, by their absorption, give rise to the Fraunhofer lines.

FIG. 4.—SHOWING THE HYDROGEN AND CALCIUM LINES REVERSED.

Here they appear as two bright streaks in broad dark absorption lines.

The chief object revealed to us by a total solar eclipse is the *corona* (Fig. 1), a great irregular glory of white light which is seen radiating in all directions as soon as the dark body of the moon has completely hidden the sun. There are a few ancient notices of it, but from the time of the eclipse of 1842 it has received careful attention at every opportunity.

Very shortly after the prominences had

been proved to belong to the sun, the corona also was shown to be truly solar; and the comparison of its form in successive eclipses has proved that it is subject

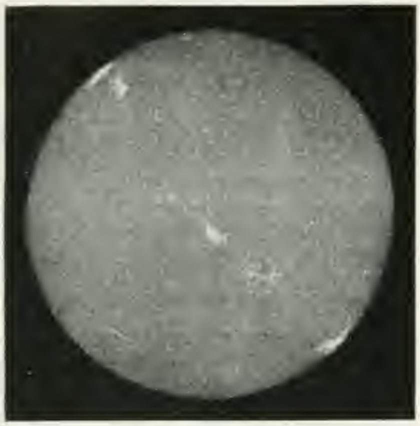


FIG. 5.—THE SUN PHOTOGRAPHED ON A K LINE WITH A SPECTRO-HELIOGRAPH BY MR. J. EVERSHED, F.R.A.S.

to changes proceeding in precisely the same cycle as that regulating sun spots, faculæ, and prominences. At the time of the solar maximum the corona is irregular in form, throwing out streamers in many directions. At the solar minimum it is much simpler in appearance; two long arms extend east and west in the direction of the solar equator, whilst round the poles of the sun a number of short feathers of light radiate in a fan-like manner. At intervening times the shape of the corona approximates to the maximum or to the minimum type in general accordance with the spotted area of the sun at that particular time.

These equatorial extensions of the corona were seen remarkably well by Newcomb in the eclipse of 1878 (July 29th), and he traced them to a distance of 11 millions of miles from the sun's centre. This striking observation gave rise to the suggestion that the Zodiacal Light—the faint conical glow seen in the west after sunset and in the east before sunrise on certain occasions—was, in fact, but the outermost portion of the corona itself. This suggestion is inadmissible. The attempt was made at a number of succeeding eclipses to photograph these great coronal streamers. M. Hansky, in the eclipse of 1896 (August 9th), photographed one of the streamers to a distance of two solar diameters. Mrs. Maunder in the next eclipse, that of 1898 (January 22nd), photographed four of these rays, one of them to a distance of very nearly seven solar diameters. This longest ray made an angle with the solar equator of 35°, the ray next in length an angle of 21°. Since the Zodiacal Light is either coincident with the sun's equator or with the ecliptic (which makes an angle of $7\frac{1}{4}°$ with it) it is clear it could have no possible connection with these streamers.

The structure of the corona has shown very clearly how intimate is the connection between the coronal forms and spots and prominences.

The spectrum of the corona has as yet shown us but little. It is partly gaseous, for some five or six bright lines are ob-

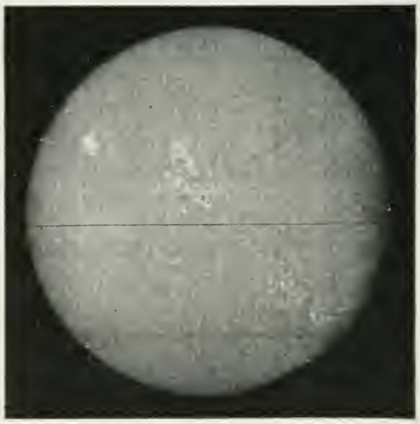


FIG. 6.—ANOTHER PICTURE OF THE SUN OBTAINED BY MR. EVERSHED.

served in it, but we have not as yet identified the elements. It would appear also partly to consist of finely divided matter, partly raised to incandescence by its near neighbourhood to the sun,

and so giving a continuous spectrum partly reflecting sunlight, and so showing very feebly some of the Fraunhofer lines.

To sum up, we find in the sun—regarded as the fire, light, and life of the solar system—an orb glowing with 150 times the intrinsic lustre of the lime-light, and emitting in every second of time as much heat as would result from the burning of 12,000 millions of millions of tons of coal. This vast fiery mass is surrounded by vapours, among which we can recognise, by means of the spectroscope, many of our familiar elements. Such elements as iron, copper, and zinc exist, then, in the form of vapour in the solar atmosphere; yet, intensely hot though we know they must be, they are cooler than the surface above which they lie, since their presence is made known by their dark lines in the spectrum. Studying the sun's surroundings, we find his complex atmosphere to be some 700 or 800 miles deep, the chromosphere 3,000 miles deep, the prominence region about 100,000 miles deep, though occasional outbursts to twice or thrice that height have been observed. The inner corona seems to be some 300,000 miles, the outer about 800,000 miles, in height, measured from the sun's surface. Lastly, there are coronal streamers which have been traced to a distance of 5,000,000 miles, but may in reality extend much further; and the whole of this vast structure changes its form and appearance in sympathy with the changes in the sun itself, of which its spots and faculæ are the evidence.

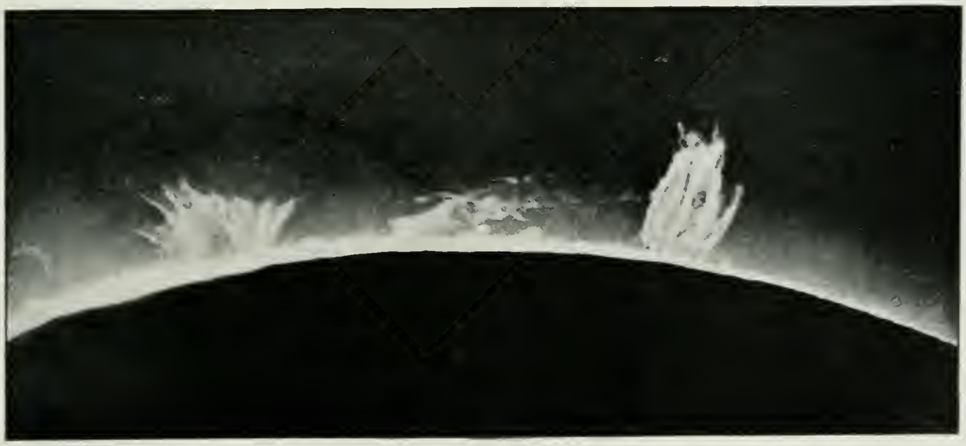


FIG. 7.—GROUP OF PROMINENCES IN S.W. QUADRANT.

Photographed through a telescope of 6 in. aperture and 61½ ft. focal length by Messrs. Barnard and Ritchley, May 28th, 1900.

THE COLOURS OF ANIMALS.

By WILLIAM ACKROYD, F.I.C.

THE modern doctrine of selective absorption accounts in a very simple manner for all the variety of colour which beautifies animate and inanimate nature. The light of the sun consists, roughly speaking, of seven colours —red, orange, yellow, green, blue, indigo, and violet—and when solar light falls on an object, if any of these constituents be absorbed, the remainder of the light which reaches the eye gives one the sensation of colour. To take a typical example. A brick house has its quality of redness because, of all the light which falls on it from the sun, only red, and perhaps a little orange, is reflected and received into the eye, the remainder of the light—*i.e.* yellow, green, blue, indigo, and violet—being absorbed or kept back by the surface of the bricks; hence the quality of the light absorbed determines the hue any substance shall have. Now, among inorganic bodies the quality of the light absorbed depends upon the composition of the substance, and when this principle is well understood it is seen that marvellous harmony prevails in the world of colour, and that there is conformity to definite laws. As regards the colours of animals, we are yet in the dark concerning many of these matters. The constitution of the pigments in hair, for example, have not yet been satisfactorily determined. Yet the colour facts of the animal world present certain analogies to those of the mineral world which are remarkable, and may reasonably be regarded as indicative of deeper likenesses. To see these things we must first possess the key to the knowledge of law and order prevailing among mineral substances.

Certain compounds of oxygen with other elements—*i.e.* oxides—are coloured, as, *e.g.*, those of the metals zinc, lead, and mercury. Their colour is strangely affected by rise of temperature. Thus, to take "mercuric oxide": orange yellow at the ordinary temperature, it changes colour when heated, and becomes orange, red, and brown successively. It is quite possible to form a progressive scale of this change, as I long ago found * that the alteration in appearance is the result of the progressively increased absorption of the rays which have their place at the violet end of the spectrum, so that the proportion of rays at the red end of the spectrum which are reflected rises higher and higher. At last they likewise are absorbed, and the end is complete absorption, or blackness.

PROGRESSIVE SCALE OF COLOUR-CHANGE.

Heating or Expanding.	↑	Black. Brown. Red Orange. Yellow. White.	↓	Cooling or Contracting

In view of the analogies which subsist between these inorganic colour phenomena and those of the organic kingdom, we shall use this scale as a means of reference in our study of the latter. It will be noted that we have the minimum of absorption at one end and the maximum at the other.

The subject of animal coloration is comparatively new, for it has not left the qualitative stage which marks the childhood of every science. The only instrument we need use therefore is the naked eye. In seeking, however, for

* "Metachromatism or Colour-change," *Chemical News*, Vol. XXXIV., pp. 76, 77. (1876.)

subjects, we must employ some discrimination, for one could deduce nothing from making any number of observations of piebald horses or domesticated rabbits. To detect uniformities, and so to form laws, we must restrict our observations to animals comparatively wild and in a natural state, or to those upon which domestication has had little or no effect. We may profitably further circumscribe our field of observation by confining our attention at first to the Mammalia, or that large class of animals which, as a rule, suckle their young, and have hairy coverings, besides other peculiarities too technical to mention here. Well, the first very general peculiarity one observes is that the ventral portions of the body are lighter coloured than the dorsal—*i e.* the back has a colour which stands nearer the black end of our scale than that possessed by the abdomen. For example, the squirrel (*Macroxus rufogaster*) has a brown back, whilst its belly and breast are red—a step nearer the white end of the scale. The same peculiarity may be seen in the common ass. whose dorsal parts are decidedly darker than those that are ventral. To see how general this peculiarity is we must go through a well-stocked museum.

This darker dorsal portion may be uniformly coloured, as in the majority of instances, or variegated by spots and stripes ; and it is remarkable that where there is striping we get an approach to and in many examples complete symmetry of marking. Examine the markings on the head of a Bengal tiger (Fig. 1). It will be found to approach a geometrical pattern for symmetry, the stripes on one side of the middle line beautifully balancing those on the other. The same symmetry of pattern is observable in the zebra, Indian tapir, aard-wolf, and even in some of our domestic cats.

Among the higher beings such as those we are now dealing with there is an "axial" part of the body from which branch off two pairs of limbs—the arms and the legs, and in continuation of this axial portion we find a tail. These appendages are for the most part grasping or locomotive organs ; and we notice they are more absorptively or darker coloured than any other parts of the body. Especially is this the case with the tail ; thus, in the squirrel already referred to, whilst the belly and back are red and brown respectively, the tail is black. Take your

FIG. I.—THE TIGER AFFORDS ONE OF THE BEST INSTANCES OF SYMMETRY OF MARKING.
Notice how beautifully the stripes balance each other.

stand at some busy crossing, and of all the horses which pass you in a given time ascertain the percentage in which the tail is darker than the axial part of the body. Fully 94 per cent. conform to the rule. Brown horses seem invariably to have black tails.

A very curious fact respecting animal coloration is that of sexual difference. It has often been asserted by naturalists that males are "brighter coloured" than females. Now, "brighter coloured" is a vague and unscientific expression, and open to grave misconception. I therefore substitute for it "darker coloured" in the sense in which we have so far employed this

phrase—viz. that of a colour resulting from a greater absorption of light. With this slight but necessary alteration, the law of sexual difference will stand thus: *the males of a given species are darker coloured than the females.*

The following table in support of this law is constructed from data supplied by Darwin's "Descent of Man. "F" stands for female, and "M" for male; moreover, blue and green are interpolated between white and yellow in the colour scale, for a reason given further on:—

	White.	Blue.	Green.	Yellow.	Orange.	Red.	Brown.	Black.
MONKEYS.								
1. Ruffed lemur (*Lemur macaco*)	...	...	...	...	...	...	F	M
2. Black howler (*Mycetes niger*)	...	...	...	F	...	...	...	M
3. White-headed saki (*Pithecia leucocephala*)	...	...	...	...	...	...	F	M
4. Chuva spider monkey (*Ateles marginatus*)	F	...	...	M	...	...	...	...
5. Hoolock gibbon (*Hylobates hoolock*)	...	...	...	...	...	...	F	M
6. White-thighed monkey (*Semnopithecus chrysomelas*)	...	...	...	...	...	...	F	M
RUMINANTS. (*Chewers of the Cud.*)								
7. Indian antelope (*Antelope bezoartica*)..	...	...	...	...	...	...	F	M
8. Sable antelope (*Hippotragus niger*) ..	...	...	...	...	...	...	F	M
9. Hartebeest (*Alcelaphus caama*)	...	...	...	...	...	...	F	M
10. Nylghaie (*Boselaphus pictus*)	...	...	...	F	...	...	...	M
MARSUPIALS. (*Pouched Animals.*)								
11. Red kangaroo (*Macropus rufus*) ... ... (*See Coloured Plate.*)	...	F	...	...	...	M	...	...

The uniformities of colouring which we have so far sketched out, as seen in the Mammalia, will be likewise found in birds and reptiles, and even in some of the lowest orders of animals—those without backbones, or *Invertebrata*, as they are termed. Thus the symmetry of marking is seen strikingly in insects. Catch a butterfly, and examine the disposition of its colours and markings. No matter what the species, it will be found to have the ornamental pattern of one side exactly corresponding to that on the other (Fig. 2). Indeed, this "bilateral symmetry," as naturalists call it, is perhaps in no case better seen than in that of these lovely insects.

The darker colour of the dorsal than of the ventral portions of the body may likewise be seen in birds, and extremely well

FIG. 2.—*URANIA SOLANUS.*
Note the symmetrical marking.

in those which frequent the water—web-footed birds. Nor does the law of sexual difference fail among birds and reptiles, as the following few facts, again taken from the "Descent of Man," will show:—

	White.	Blue.	Green.	Yellow	Orange.	Red.	Brown.	Black.
BIRDS.								
Stork of genus *Xenorhynchus* .. .. eyes	...	...	...	F	.	..	...	M
Hornbills (*Buceros*) ... ,,	F	...	...	...	.	M	...	...
Condor ... ... ,,	...	...	...	...	..	F	M	...
LIZARDS.								
Calotes nigrilabris ... lips	...	...	F	...	...	...	...	M
Zootoca vivipara (under side of body	...	...	F	..	M	...	...	...
SERPENTS.								
Dipsas cynodon	...	...	...	...	...	F	...	M

In speaking of the limbs and tail, it will not require much thought to see that those belonging to a mammal have exactly corresponding parts in a bird, and taking the squirrel (*Macroxus rufogaster*) and a robin redbreast as examples, we might make some such comparison as the following:—

Squirrel.	
Back	brown.
Belly and breast ...	red.
Front leg flanks inclined	to black.
Tail	black.

Redbreast.	
Back	brown.
Belly ...	light coloured.
Breast	red.
Wings ...	dark brown.
Tail tip ...	dark brown.

Such a comparison is not fanciful, as the deeper teaching of anatomy tells us that a mammal's front legs are the appendages which correspond to a bird's wings. The correspondence of the other parts is manifest even to common observers. The point, however, to be noticed is that the wing and the tail tip are darker than the rest of the body; or, as we expressed it in the case of the Mammalia, the appendages are more absorptively or darkly coloured than any other part of the body.

The causes at work producing these uniformities in colour are hidden from us, and to discover them will doubtless furnish much work for future investigators. There are, however, phenomena which seem to give us an inkling as to what they may be, and these phenomena we will proceed to consider.

With the approach of winter in the Arctic regions there is a gradual change of colour in many of the animals—*e.g.* the Arctic fox and ermine (Fig. 3), and they become as white as the snow they tread upon. Even certain quadrupeds which do not take on a white winter dress become, according to Pallas, of a paler tint. This celebrated naturalist states that in Siberia such a change occurs in the wolf, domestic horse, domestic cow, musk-deer, elk, roe, reindeer, and many other animals. The roe, for example, has a red summer coat and a greyish white winter coat. Now, it is very tempting to think that the first persistent feeling of cold which these animals experience when the season alters gives rise to such a change in the skin as is competent to produce an alteration of colour; in other words, that the change is a product of reflex action. There are examples of colour change in which there cannot be the slightest doubt of this being the case. Thus, the chameleon, about which such wondrous tales have been told, will alter the colour of its coat to some extent when light is allowed to fall on it. Fig. 5 is illustrative of an experiment on this point made by Bert. The chameleon was placed in full sunlight, care being taken

FIG. 3.—ARCTIC FOX AND ERMINE.
These two animals change the colour of their fur to white upon the approach of winter.

that the light illuminating the fore part of the body should pass through red glass, whilst that falling on the hind part had to pass through blue glass. The body seemed divided into two parts—the anterior of a clear green with red spots, and the posterior of a darkish green. Here it is evident that the "feeling of light," if one may use the phrase, was transmitted to the central nervous organ, and the disturbance was then reflected back to produce an alteration in the appearance of the skin. In another example a sleeping chameleon was placed under the influence of strong lamplight, whilst the dorsal part of the body was protected by a screen. In this way the singular appearance given in Fig. 6 was obtained, where the head, neck, feet, abdomen, and tail are of a darkish green, and the protected portion appears like a brownish saddle.

FIG. 4.—THE BROWN BEAR.

That colour is regulated by some deeply seated and symmetrically distributed portion of the organism, such as the nervous system, seems not improbable likewise when we come to think about those cases of symmetrical colouring which we have already briefly referred to.

In the case of the chameleon, direct experiments have been made which show that, at any rate in this animal, the colour is governed by the nervous system. In one experiment of Bert's it was found that if by any accident the spinal cord of a chameleon was severed (as at *A* in Fig. 7), the fore part of the body was green, whilst the posterior became black. Plainly, here the breaking of the nervous continuity caused the dissimilarity of tint between the two parts of the body. Again, when two or three sections were made of the spinal cord and stimuli applied, it was found that those portions of the body to which the stimulated nerves led became of a clear green, whilst the part of the body where the nerves had not been excited remained of a sombre tint.

It was the opinion of the late M. Bert that a set of nerves similar in their working to the *vaso-motor* nerves are those which play the important part of making the integument vary in colour under suitable circumstances.

Extraordinary changes of tint are seen sometimes when certain fishes die. Pliny narrates that the ancient Romans, who esteemed the gold-fish (*Mullus barbatus*) a great delicacy, would not dine off it until

they had seen it die, its exhibition of the various rainbow hues affording them much amusement, and, in fact, being one of its chief merits.

Respecting the ultimate nature of this change, we can only for the present make

FIG. 5.—CHAMELEON UNDER SUNLIGHT PASSED THROUGH RED AND BLUE GLASS.

surmises. It may, probably, be of the same nature as that inorganic colour change we have already described; and, at any rate, there is a striking resemblance between the two phenomena. We have seen that when certain inorganic bodies are heated they change colour in a particular order, and that when they cool they regain their old tints. Now, the change of structure which we have here

FIG. 6.—CHAMELEON UNDER LAMPLIGHT.

In this case the back is protected by a screen.

may probably be effected by other agents besides heat. It only requires the scratch of a pin, or the slightest disturbance, to change the yellow iodide of mercury into a scarlet modification, and it is conceivable that in the organic world expansion and contraction of the component parts of the organism may be effected by other means and in other ways than those we employ for coloured oxides. Only this we look for—that where we have expansion, there we ought to get increased absorption; where we have contraction, there we ought to have decreased absorption. In the case of the chameleon, it seems a remarkably confirmatory fact that green and yellow are acquired when what we may term the compressing nerves (those which act like Bernard's *vaso-constricteurs*) are at work, and that sombre tints are assumed when the expanding nerves (those which play the part of Bernard's *vaso-dilatateurs*) are concerned.

Again, death in animals is generally

FIG. 7.—CHAMELEON WITH SPINAL CORD SEVERED AT *A*.

The fore part of the body now appears to be green and the hind part black.

accompanied by a sort of contraction, known as the death stiffening or *rigor mortis*. Now, when fishing for mackerel, if the tint of one freshly caught be compared with one that is dying, the former appears of a sort of sea-green, and the latter of a deep blue. That this change denotes contraction is better seen when we compare it with the behaviour of a hot borate of copper bead, which is green, and, as it cools and contracts, becomes blue. Blue and green were interpolated in the scale given on p. 528, in order to include this borate change.

It may be that ultimately we shall be enabled in some such manner to explain

the deepening of tint observed in animals passing from youth to the adult state; the acquisition of grey and white by those passing to old age, and the similar, but sudden, change which has been brought on at times by great privation or acute distress. In a paper read at the Plymouth meeting of the British Association (1877), I attempted to carry this analogy farther, by regarding colour change as evidence of alteration of *energy*. Energy means the power to do work, and just as we impart energy to water when we heat it—energy which may be turned to useful purposes by means of the steam engine—so we no less impart energy to an oxide when we heat it; and the colour change is an ocular evidence of this transference of energy. Applying, then, this idea to the subject in hand, we may regard colour change, where there is an increase of absorption, as evidence of increase of animal energy; and, on the contrary, where there is a decrease of absorption, not for climatic purposes, as evidence of decrease of animal energy. For this purpose our scale would stand thus:

Increase of animal energy.	↑	Black. Brown. Red. Orange. Yellow. Green. Blue. White.	↓	Decrease of animal energy.

We ascend the scale from less to more absorptive colours when an animal changes from its cubhood to the adult state. To take an example: the young of the howler monkey, known as *Mycetes caraya*, are of a greyish yellow; in the second year they become reddish brown; in the third year they are black all over, save the stomach, and after this the stomach becomes black too. The change is typical, and may be seen in other animals, even in man. Many a man with red, brown, or black hair had as a child yellow locks.

On the other hand, when the prime of life is past, when life is on the wane and energy decreasing, a change is seen in the opposite direction — the hair becomes grey or white. Such a change to greyness has likewise been observed in the fox and dog, horse and hare. To keep up the analogy, one would naturally expect some such change where there is an excessive strain on the vitality, produced by sudden fear or great privation; and it is noteworthy that many of the survivors of the wreck of the *Strathmore* had the colour of their hair temporarily changed by the sufferings and anxiety they had undergone. Black hair became brown and red, and fairer colours were changed to white and flaxen.

We may now conclude with a few words on the uses of these colours to the animals which possess them. There can be no difference of opinion as to the use of a hairy covering, for it evidently serves the same end as clothes by keeping the body warm. Now, we change our garb with the season, as we find by experience that a light, airy suit is much fitter for summer wear than the dense, heavy materials we employ in winter. It is not unreasonable to think, therefore, that it would be conducive to the well-being of animals in the Arctic regions if they could be protected against the cold, which is at times so extremely severe as to freeze mercury as hard as a stone. It may be that the winter change to snow-white answers this purpose. Such a supposition receives some support on physical grounds. We know that good absorbers of heat readily give off the heat they have absorbed. A good absorber of heat would therefore be ill fitted to keep the animal frame in a warm and comfortable state in a cold region. On the other hand, we are equally certain that a bad absorber of heat does not readily part with the heat it possesses. Therefore a bad absorber of heat would be well adapted for keeping an animal warm. On these grounds it is not improbable that the

badly absorbing white fur is much fitter for winter wear than the dark and heat absorbing summer coat. The former would economise animal heat at a time when food is scarce and the atmosphere rigorously cold; the latter would readily part with surplus heat when food is plentiful and climatic conditions are comparatively mild.

It is supposed by naturalists that this snow tint of Arctic fauna is a protective colouring — *i.e.* that an animal is concealed by its resemblance to the snow from the enemy that would prey upon it. Such an idea is in no way inconsistent with the hypothesis of "climate protection" just advanced, but it is beset by the formidable difficulty that a colour which conceals both enemy and prey favours one in the same measure as the other.*

FIG. 8.—THE POLAR BEAR AT HOME.

The dermal covering may be regarded as a sort of heat economiser governed by the nervous system; and one can quite understand that if the atmospheric conditions rendered it necessary the white coat would be retained the whole year round. As a matter of fact, naturalists have found that the changing hare (*Lepus variabilis*) retains its shining white fur in Scotland until the month of March, or even later, according to the temperature. Taking this view of matters, we may regard that difference of tint between dorsal and ventral parts, to which we called attention in the fore part of the paper, as due to a similar cause. Thus, the ventral parts being constantly turned towards the cold ground, must, by radiation and direct contact, be constantly in need of a warm covering. Hence, the white abdominal fur may be induced in the same way, and have to serve the same end, as the snow-white garb of the Arctic bear (Fig. 8).

The sandy colours of many desert-frequenting animals, the green colours of birds and reptiles living in tropical forests, and the remarkable tints of many insects are regarded as examples in which the colours are protective, by affording concealment either from their enemies or from the creatures they prey upon. It may be that many of these are real cases where protection is derived; some, however, are open to doubt. The colour-changes of the chameleon have not been found to be so sudden or so extreme as imaginative writers were wont to describe, and the idea of protection, is now regarded with some disfavour.

* This is fully discussed in "Nature's Riddles," by H. W. Shepheard-Walwyn, F.Z.S.

HYDROGEN, THE WATER PRODUCER.

By WILLIAM ACKROYD, F.I.C.

HYDROGEN is the most widely distributed element in the universe. We look up at the "Milky Way"; the astronomer tells us there is spectroscopic evidence of hydrogen there, and that the atmosphere of the sun also shows its presence during total eclipses. In its function as water producer it forms a ninth part by weight of water. If we take this figure and reckon the weight of the hydrogen in the oceans we shall find that they contain some 147,000 billion* tons of it The air we breathe has a trace which amounts to about ·0002 of its volume, according to Gautier. We may say that it is a component part of every animal and vegetable in the world. It possesses the unique quality of being the lightest of all known elements, and this property alone makes it probable that it is more plentiful in the outer planetary members of the solar system than in the earth itself. The gradually rising balloon, with its car full of venturesome voyagers, is a practical demonstration of its lightness, as the bouyancy of the balloon is due to the coal gas with which it is filled containing some 38 per cent. of hydrogen. Before coal gas was used aëronauts made hydrogen for the purpose from scrap-iron and sulphuric acid. The first balloon sent up in England—on November 25th, 1793—was filled with hydrogen. Our neighbours across the Channel followed suit next year at Meudon; but the use of sulphuric acid for making hydrogen was soon forbidden in France, as all the available sulphur was wanted in those stirring times for making gunpowder. Then hydrogen had to be made from water by passing steam over red-hot iron.

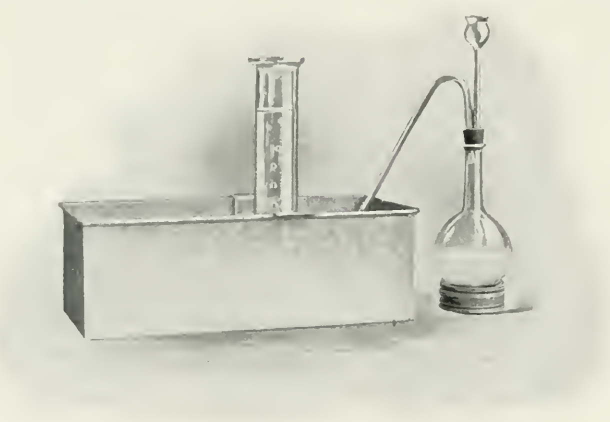


FIG. 1.—HOW HYDROGEN IS MADE.

A flask containing a little zinc is fitted with a cork carrying a delivery tube and thistle funnel. Dilute sulphuric acid is poured in, and the gas is collected over the pneumatic trough, as shown.

Hydrogen is a colourless, tasteless, and transparent gas. Diluted oil of vitriol or sulphuric acid with a metal like zinc or iron is still the readiest mixture for yielding it. The apparatus required is shown in Fig. 1.

A flask is fitted with a cork with two holes, and through one is thrust a thistle-headed glass tube (*t*, Fig. 2), and through the other a bent piece of glass known as a delivery tube, *d*. Both must be gas-tight. Zinc is put in the flask, and covered with water, and then the cork with its tubes is fitted tightly into the flask neck. The dilute sulphuric acid is now poured a little at a time down the thistle-headed tube,

* 147,000,000,000,000,000.

until there is brisk effervescence. Hydrogen is liberated, and if the end of the delivery tube dip into a trough or bowl of water, as shown in Fig. 1, it will be seen to issue in rapid bubbles. A number of vessels may now be filled with water, and brought, mouth downwards, one after the other, over the end of the delivery tube, whence the hydrogen is issuing. As soon as they are filled they had better be removed, and closed by covering the mouth of each jar with a piece of glass, and then conveying it to the table *mouth downwards*, and letting it rest there in that position until wanted. Now remove a jar with its mouth upwards, take away the cover glass for a few seconds, and then apply a light to the contents of the jar ; nothing happens, as all the hydrogen, on account of its lightness, has escaped. Next push a lighted spill of wood right up into another of the jars. The hydrogen burns at the mouth, but the lighted spill is put out. This experiment shows that although hydrogen itself will burn quietly in contact with air, it does not support the combustion of burning wood (Fig. 4).

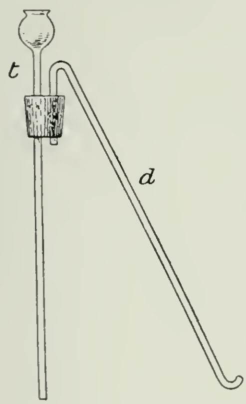


FIG. 2.—CORK BORED TO TAKE DELIVERY TUBE (*d*) AND THISTLE TUBE (*t*).

FIG. 3.—A PELLET OF BURNING POTASSIUM FLOATING ON WATER.

The question is naturally asked, "Why does the hydrogen burn ?" In the air there is a gaseous element called oxygen, and when hydrogen burns it is chemically combining with this oxygen and forming water. There are many experimental proofs of this, but the following will suffice :

To the end of a short delivery tube, whence hydrogen is issuing, let a piece of rubber tubing be attached, and at its other end be joined to an arrangement whereby it can be issued as a jet (Fig. 5). Apply a light to the jet of hydrogen, and notice, by the way, that it burns with a comparatively colourless flame, so that it can only be seen with difficulty. Now hold a cold glass bell-jar over the burning jet of hydrogen ; the inner surface is soon covered with a dew, which may be proved to be water (Fig. 6). The next experiment is equally conclusive. Some metals when heated in air combine with the oxygen in it to form one of the class of compounds

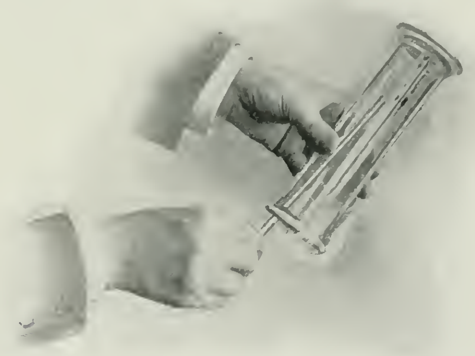


FIG. 4.—HYDROGEN BURNS WITH A PALE BLUE NON-LUMINOUS FLAME OF HIGH TEMPERATURE.
Notice that the hydrogen burns only at the mouth of the jar, where it comes into contact with the air; it does not support combustion.

known as oxides. Copper-wire, when strongly heated in a current of air, is covered with a black deposit of copper oxide. Now if the gas hydrogen be passed through a tube containing this compound while it is being heated it will be found to regain its red colour; it is no longer oxide—it has lost its oxygen, and farther on, in a cool part of the tube, water is found to be deposited in drops (Fig. 7). The water, which is here chemically formed, may be collected by passing the vapour down into a cold test-tube, and when it is there it may be tested by dropping a piece of potassium into it, as will be described presently. By certain refinements, this experiment can be made *quantitative*. When the tube containing the oxide is weighed before and after the experiment the loss is the quantity of oxygen which has been used up to form water. If all the water which is formed is also weighed, we get by subtracting the weight of oxygen the amount of combined hydrogen.

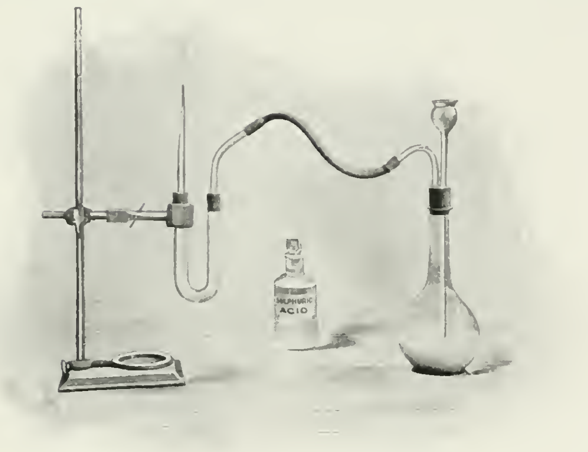


FIG 5.—BURNING HYDROGEN.

The generating flask is connected by rubber tubing to a U-*tube, containing cotton wool moistened with benzene. A light is applied as shown.*

In this way it is found that one part by weight of hydrogen combines with eight parts by weight of oxygen to form nine parts by weight of water. The simple combination of oxygen and hydrogen in the burning is thus represented:

$$2H + O = H_2O,$$

which is to be read: "Hydrogen and oxygen yield water." This is a chemical equation, and is also to be regarded *quantitatively*. The atom of hydrogen being taken as the unit of weight, and H representing one atom, 2H represents two atoms, or two parts by weight of hydrogen. Similarly O represents one atom of oxygen, which is sixteen times heavier than an atom of hydrogen, so that the equation may also be read as follows: Two parts by weight of hydrogen and sixteen parts by weight of oxygen yield eighteen parts by weight of water—H_2O representing the molecule of water formed from two atoms of hydrogen and one atom of oxygen.

FIG. 6.—HYDROGEN, THE WATER PRODUCER.

If a cool glass jar be held over the flame of burning hydrogen, water is formed and condenses on the sides of the jar. That it is really water is proved by testing with anhydrous copper sulphate, which it turns blue.

These quantitative relations are well

shown when water is decomposed by electricity. This is done by having platinum wires or foil in water acidulated with a few drops of sulphuric acid, and passing a current of electricity between them. From one of these platinum terminals comes hydrogen, and from the other oxygen in the proportion of two measures of the former to one of the latter. These gases have been weighed with rigorous accuracy, and oxygen has been found to be sixteen times heavier than hydrogen, so that here, converting our measures into weights, we have sixteen parts of oxygen to two of hydrogen resulting from the decomposition of water.

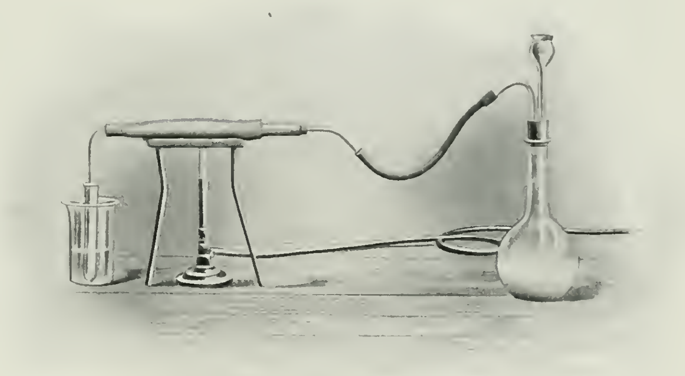


FIG. 7.—A STREAM OF HYDROGEN IS PASSED OVER HEATED COPPER OXIDE. THE OXIDE REGAINS THE RED HUE OF COPPER, AND WATER IS FORMED.

As water contains hydrogen, the latter might be liberated if a metal could be found with so strong an attraction for the oxygen that it would combine with it and displace the hydrogen. The metal *sodium* will do this. Sodium is as soft as cheese, and lighter than water. If a piece be cut from a small lump and thrown on to the surface of water in a tumbler, it will not sink but will float about. Apply a light to the floating globule, and it apparently takes fire, and burns with a yellow flame. It is the escaping hydrogen which takes fire, and the sodium which imparts to the flame the golden yellow colour. A piece of the metal *potassium* similarly thrown on to the water floats, liberates hydrogen, and generates sufficient heat to set fire to the hydrogen without any extraneous light. It imparts a violet colour to the burning hydrogen. This experiment may be employed as a simple test for water, as already suggested.

A practical question crops up here. If we can impart colour to the burning hydrogen flame, can we make it luminous? A ready reply is obtained by slightly moistening some cotton-wool with benzene, and making hydrogen gas pass through it before it reaches the jet to be burnt (Fig. 5). On now burning it, it is seen to yield a highly luminous flame. We have here the secret of the luminosity of coal gas. The components of the mixture forming coal gas are usually classified in the following manner :—

1. *Illuminants*, as *e.g.* benzene (C_6H_6), acetylene (C_2H_2), and ethylene (C_2H_4).
2. *Diluents*, as *e.g.* hydrogen (H), marsh gas (CH_4), and carbon monoxide (CO).
3. *Impurities*, as *e.g.* sulphuretted hydrogen (H_2S), carbonic acid gas (CO_2), and ammonia (NH_3).

It is the object of the condensers, scrubbers, purifiers, etc., in a gas-works to eliminate these last with the least possible interference with the two former classes of bodies. An ideal method of making gas for illuminating purposes would be to manufacture hydrogen on a gigantic scale and to impart to it illuminants, so that it would yield a good light on burning. An approach to this is obtained in the manufacture of *carburetted water gas*, but unfortunately the

hydrogen is mixed with a proportion of poisonous carbon monoxide (CO), a larger proportion than exists in ordinary coal gas.

The following comparison of the approximate quantities of diluents in the mixed gases constituting coal gas and carburetted water gas will be of interest :—

	Coal Gas.		Carburetted Water Gas.
Hydrogen (H) ...	38 to 48%	...	48%
Carbon monoxide (CO) ...	12%	...	36%
Carburetted hydrogen (CH_4)	34%	...	1%

This manufacture of hydrogen on a large scale mixed with other gases under the name of carburetted water gas has been extensively introduced in all our large towns of late years. In the gas-works you see before you what appear like steam boilers set up on end. In one of these coke (carbon, C) is fanned into a white heat ; then steam (H_2O) is passed through it. There is decomposition, and the mixture of gases resulting consists mainly of hydrogen (H) and carbon monoxide (CO) — the equation expressing the change is as follows :

$$H_2O + C = \underbrace{CO + H_2}_{\text{Water gas.}}$$

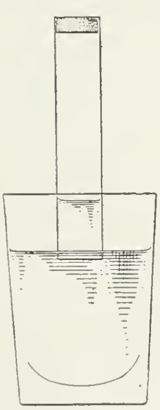


FIG. 8. — SHOWING DIFFUSION OF HYDROGEN.

Note the rising of the water in the glass tube.

Illuminating power is conferred on the mixture by passing the gases over red-hot bricks on which oil is being sprinkled ; this operation takes place in the next boiler-like iron vessel. After purification the carburetted water gas is passed into a gasometer, and can be used apart from, or along with, coal gas. Municipalities with a due sense of their responsibility do not use too much of it, as this mixture, diffusing or escaping from leaky joints into a house, is much more poisonous than coal gas, on account of the greater quantity of carbon monoxide present in it. From some of our gas-works two or three million cubic feet of it can be turned out in case of emergency in a few hours when continuous darkness has exhausted the supply of coal gas and the supply from the retorts is no longer equal to the demand.

FIG. 9.—COLLECTING HYDROGEN BY UPWARD DISPLACEMENT OF AIR.

We have by no means exhausted our account of the properties of hydrogen, and it is essential to describe one or two more. It forms an explosive mixture with air, which can be proved by admitting air to a jar partly filled with hydrogen and applying a light. On account of its being rather over fourteen times lighter than air, it can be collected in open vessels by simply passing the gas up to the closed top. In Fig. 9 there is a representation of a bell-jar being filled in this manner. A glass tube has been joined by rubber tubing to the delivery tube of the hydrogen generating apparatus. The piece of apparatus close by is for demonstrating the rapid diffusion of hydrogen. It consists of a two-necked bottle containing coloured liquid ; tightly fitting corks are adjusted in each neck, and through one of them a glass tube passes which at its upper end is joined in an air-tight way by means of

a tin cap to a porous pot—such as is used in electrical batteries. The cork in the other neck has also a glass tube passing through it, and in this case dipping into the liquid ; at its other end it is drawn out to a capillary tube. Now, on bringing the bell-jar filled with hydrogen over the porous pot, the hydrogen rushes through its walls faster than air can come out. The increase of pressure within shows itself by forcing the liquid up the other tube and out at the fine end in drops or a thin stream (Fig. 10). This experiment can be shown almost equally well by means of coal gas, and, indeed, without so elaborate a piece of apparatus, in the following simple manner. Procure a glass tube about 6 inches long and ½ inch in diameter ; now make up a thick paste by rubbing together a little plaster of Paris and water, and roll it out into a thin layer ; press one end of the tube into it, and then withdraw. A thin plug of plaster is left in the tube, which soon sets, and when thoroughly dry it may be used for the demonstration as follows : Hold it over the end of a gas burner for a few seconds while the gas is turned on ; it fills up with gas. Now close the end with the thumb, and remove it to a glass of water (Fig. 8). The water begins at once to rise in the tube above the level of that in the tumbler. Why ? Because the gas has rushed through the porous partition of plaster faster than air can come in through it, and consequently there has been reduced pressure inside the tube, and the atmospheric pressure remaining the same has forced the water upwards into the tube. It will now be understood how readily gas will pass through earth or plaster from a defective gas-pipe.

Hydrogen in the old chemistry books is described as a permanent gas. At the very low temperatures now obtainable (making a near approach to, but never reaching, the absolute zero, $-273°$ C.) hydrogen has been liquefied. The liquid boils at $-252°$ C., and effects a wonderful alteration in the appearance of many substances : thus red bromine liquid is changed to a yellow solid, which gradually becomes white. It is a temperature not pertaining to this globe, and one more likely to exist on the confines of the solar system out in ethereal space, where universal *whiteness* probably prevails.

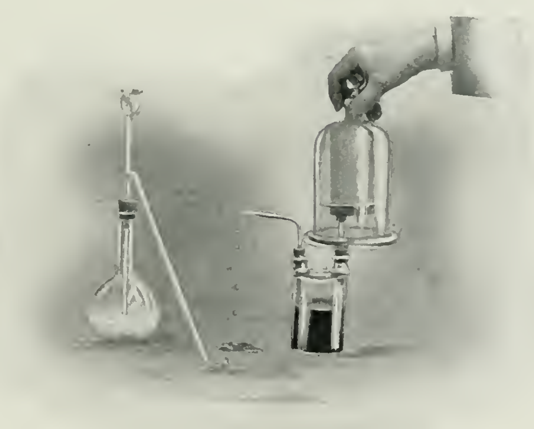


FIG. 10.—A DEMONSTRATION OF DIFFUSION : HYDROGEN PASSING THROUGH THE WALLS OF A POROUS POT.

EARTHQUAKES.

IT can easily be imagined that these awful upheavals were in the ages of universal ignorance attributed to supernatural causes, and it is curious to note that a common belief existed in countries remote from one another that the mischief was caused by the anger of some subterranean monster. In one country a gigantic spider was the originator of the trouble; a hog was the prime mover in another; it was perhaps more consistent to regard a monstrous mole as the malevolent being who caused these underground disturbances, as was the case in another quarter; while the elephant, on account of his bulk and strength, was supposed by others to be the force which lifted up the ground.

A few philosophers in ancient times ascribed earthquakes to natural causes, but in the Middle or Dark Ages the old belief was current that they were due to supernatural agency. Many theories have been suggested to account for earth disturbances, and of these a few may be selected as specimens.

(1) That they were caused by subterranean clouds bursting into lightning and shaking the caverns or vaults in which they were confined.

(2) That the pent-up forces which moved the ground found their origin in exhalations from nitre, bitumen, sulphur, and other combustible substances.

(3) That they were due to electricity.

(4) That they are caused by steam generated by the access of water to sources of subterranean heat.

None of these theories is worthy of consideration, except, perhaps, the last, which brings us to a point of considerable importance—namely, the connection between earthquake shocks and volcanic phenomena. Volcanic outbursts have often been associated with earthquakes—the eruptions of Vesuvius, for example (notably that of 1872), being generally accompanied by destructive shocks. The more recent catastrophes in the West India Islands, which culminated in the awful holocaust at Martinique, were also associated with earth tremors and earthquakes. Where a volcanic eruption takes the form of violent explosions, as in the cases just cited, and as exemplified in a still more marked manner at Krakatoa, in the Straits of Sunda, in the year 1883, earthquakes form a necessary part of the phenomena.

Earthquake shocks of this character are common round about centres of volcanic action; but the origin of the majority of earthquakes must be found elsewhere, for we find that such movements are common in countries which are far removed from volcanic influences—Switzerland and the Himalaya region, for example. Professor Milne, who is now the greatest authority upon earthquake phenomena, and who spent many years of his life in Japan, where earthquakes of more or less intensity are of daily occurrence, asserts that an analysis of some ten thousand earthquake observations in that country reveals the fact that very few had their origin near to the volcanoes. In the awful earthquake which took place in Japan in October, 1891, by which in one half-minute ten thousand persons were killed and double that number maimed, while one hundred and twenty-eight thousand houses were wrecked, it was noticeable that the many volcanoes which are situated

in the country were quiescent, and, as far as could be observed, were quite unaffected by the disturbance.

Professor Milne dwells upon the circumstance that in Middle Japan, where this catastrophe occurred, there are no volcanoes, but that every year there are at least 500 earthquake shocks. These disturbances, which are of daily—almost hourly—occurrence, do not come from the volcanoes. He states it as his belief that "a complexity of causes may enter into the production of earthquakes," and that it is not unlikely that they represent interruptions in that general process of elevation or subsidence which is in progress in many parts of the globe.

There are some of the earthquake tracts—those in the volcanic regions of South America and the islands of Java and Japan, for instance—where the shocks are so frequent, some being very slight and others great, that no relation between the seasons and the phenomena can be made out. Elsewhere it appears that there are two marked periods in every century (calculating for the last three hundred years) when the earthquakes are most numerous and intense, and one occurs in the middle and the other at the end of that lapse of time. The shocks of the greatest intensity are in the middle period, but it must be understood that in the intermediate time, when there are fewer earthquakes, this does not relate to their intensity. A great and most destructive shock may occur irrespectively of time. Usually a great intensity of earthquake action commences rather suddenly, but it does not subside with the same rapidity, for slight shocks occur one after the other, and

Photo: J. Winterton, Junr.

FIG. I.—RESULTS OF AN EARTHQUAKE IN A TOWN IN GUATEMALA, CENTRAL AMERICA.

occupy some time before the ordinary state of things returns. There is some reason to believe that at least one great earthquake, extending over more than 1,000 miles, occurs every eight months, and that at least 200, and probably very many more, earthquakes of different intensities occur in the year. In the northern hemisphere there are fewest earthquakes in the summer, and the time of least subterranean action is, according to Robert Mallet, in May, June, and July, while the greatest activity is shown in December and January, so that the preponderance of power to shake is in the winter. Again, Perrey and Mallet show that between December 11th and 31st, or in what is termed the winter solstice, and between March 10th and 30th, or the vernal equinox, there are the greatest number of earthquakes. The periods of earth repose are at the summer solstice and autumnal equinox. These curious results of many observations are as interesting as those which show that there is a correspondence between the pressure of the atmosphere and earthquake phenomena, the "high glass" produced by increased atmospheric pressure being accompanied by earthquake phenomena. But Mallet suggests that there may be no connection between the pressure of the air and the origin of the earthquake, and he notices that the local increase of atmospheric pressure in one locality and its diminution in a neighbouring one may produce volcanic action which is in direct relation to the earthquake. The researches of Perrey rather tend to show that when the moon is nearest the earth the earthquake shocks are the severest, and this statement may be of the same value as that regarding the influence of atmospheric pressure. They both relate clearly to the theory of the cause of earthquakes. Some tremors are so slight that they are not felt over many miles; others are felt far and wide; and all may be classed as great, middle, and slight, according to the distances along which they are felt. Great earthquakes, which destroy cities and produce alterations on the surface of the earth, may have an extreme radius of 540 geographical miles, or 9°; that is to say, they circle on all sides from a centre, and the circle, when measured across, is 18° of the earth's surface, or 1,080 geographical miles. The Lisbon earthquake is an instance of this kind. The mean earthquakes produce much less destruction, and rarely cause loss of life, producing little change in natural objects; they have a radius (a line from the presumed centre of disturbance to its remotest part) of 3°, or 180 geographical miles. Finally, the minor earthquakes, which leave few or no results of their shock, extend over some sixty geographical miles, or 1° in radius.

When an earthquake occurs, and its details are recorded carefully, it is said to *pass* in a certain direction, and the expression is used, "The shock passed" from some direction of the compass to the opposite: from N.E. to S.W., for instance. In some districts, where the shocks are moderately frequent and slight, the direction is almost invariably the same; and even in countries where more severe shocks are felt, it often happens that they take a definite line of country, passing along mountain chains and along river valleys, and ceasing sometimes abruptly where the nature of the geology of the district changes. Sometimes, however, it happens when the earthquake is severe that it is felt along very different directions, and the movement is from a centre and radiates in all directions. Starting from some spot, the shock is felt on all points of the compass around it, and the shake is carried along mile after mile, spreading, as it

were, in broad circles, but ever moving directly forward in lines. The record will then state that the shocks were felt from such a place moving from S. to N., and in the opposite direction. N. to S., and from W. to E., and E. to W., etc. In reality, all earthquakes start from what may be called a centre and radiate in all directions, but the nature of the ground causes the shock to be severely felt in some, and to be stopped or greatly diminished in other places. Under all circumstances the intensity of the shock is greatest nearest the centre from which it *appears* to start, and it diminishes gradually with space, and is at last not felt. The movement in the earth which constitutes the shock travels most readily along solid parts of the crust, and is interfered with by softer portions intervening between the denser, or by changes in the nature of rocks. A mountain chain is, of course, a comparatively solid structure, and the continuity of the earth in a valley is usually perfect; hence the shock is carried along them readily. But if the mountain chain ends in a great collection of soft earth, or in low hills of gravel or mud overlooking a plain, the movement is checked there more or less. A deep valley will extinguish the shock. With regard to the sea, it is evident that the great earthquake waves have an origin in the movement of the floor of the ocean which is carried out in the very movable water. The waves extend in increasing circles from one spot situated deeply, and every particle of the water on the surface which assumes the movement called a wave moves upwards, forwards, and then more or less downwards and backwards towards its original position. In fact, the sea is thrown into the same kind of movement, which is infinitely less perceptible on land, in consequence of the comparative immobility of the particles of rocks and earth. But whilst it is evident that the movement begins deep down in the case of the sea, it is not so readily apparent where it starts from on land. In both instances the movement appears to travel on the surface in a radiating manner, and has apparently more or less regular directions. An examination of the cracks and fissures of buildings which had been produced by earthquake shocks (Figs. 2 and 5) showed Mr. Mallet that this surface radiation, or travelling of the shock in certain directions, was not such a simple thing as might be at first imagined, and that really there is not a direct movement from one point to another along the ground. A city or

FIG. 2.—EARTHQUAKE EFFECTS IN MANILA.

a house destroyed by an earthquake is a terrible scene of desolation, but there is a remarkable order in the destruction and disorder produced. The buildings are split and cracked in certain definite directions; pillars and monuments fall and walls tumble in positions which refer to the path of the earth movement. A very striking proof of the deep seat of the commencing earthquake shock—that is to say, of the origin of the movement—was given in describing some of the results of the Calabrian phenomena. It was stated that masses of earth were cast upwards, and the paving-stones of some towns were found lying with their lowest sides uppermost, whilst there were well authenticated instances of the upward casting, to the height of some feet. of loosely lying structures. To cast up a paving-stone some feet so that on falling it shall turn upside down can only be done by a force acting from below like a sudden blow; such a force would have a special direction, which would be almost vertical—that is to say, from below directly upwards. The cracks in buildings were often found to be parallel with each other, as if the force had struck the edifice, not sideways along the ground, but from below through the earth, lifting it partly and splitting it across the direction of the force. Now, by taking the direction or lines of the cracks, and drawing an imaginary line at right angles to them into the earth, the direction of the shock or movement can be ascertained. This line plunges down very abruptly in some instances, and in others slopes more gently towards the ground. It makes an angle where it enters the earth, which becomes less and less with distance along the earth from the seat of the deeply originating shock, so that sooner or later the force comes so obliquely out of the earth, or rather, is felt so by buildings, etc., that it appears to travel horizontally along the ground.

Mr. Mallet, by examining the direction of the cracks in many ruins in opposite directions of the compass, found that the imaginary lines drawn by him at right angles to them into the earth, tended to approach each other if they were sufficiently prolonged in a diagram or plan, and that they pointed to the focus, or place of origin, of the earthquake, which was always at a considerable depth. The instance given of the capsized paving-stones occurred over what is called the *seismic vertical*, or in a straight line immediately over the focus. The shock which does the mischief is, of course, first felt on the surface at the shortest distance from the focus or immediately above it; the last feeling of the shock is miles and miles away from this seismic vertical. Between the seismic vertical and the remote spot the shocks come up to the surface one after the other with great rapidity. Starting from the focal space, the movement is along a succession of more and more slanting series of particles, and it reaches the surface at the same time in circles around the vertical point over the focus. The emergence of the movement from below becomes more and more oblique as the circles enlarge, and, what is very important, the intensity of the movement diminishes in a correponding manner. So rapidly do the particles move from below upwards in the successive circles, and so rapidly does each particle return to its place in the same direction, that a wave-like movement is produced along the ground, moving on all sides from the seismic vertical. The rapidity of that movement can, of course, be measured by comparing clocks at different shaken places on the circles. If a line be drawn through the circles and through the seismic vertical, it will be one along which the wave or apparent along-surface movement will progress from the position of the first shock. Whenever the line cuts a circle to the right or left (or in

any opposite directions) of the vertical point, there the shock will be felt simultaneously. The circles are termed *seismic circles*, and the points of simultaneous shaking or of particle movement are *co-seismic points*.

If a diagram be drawn to illustrate the nature of the movement in the underground rocks from the earthquake focus to the surface, radiating lines would represent the general direction of the movement.

The British Isles are happily free, or almost free, from earthquake shocks, and such as have been felt in this country have been of a very slight character indeed when compared with those which seem to be constantly occurring in other parts of the globe. About 300 small earthquakes have been recorded here, and it may be presumed that the greater majority of these were tremors unaccompanied by damage to property or other marked effects. Minor tremors, which are only recognised by the use of special recording instruments, may be said to be of almost daily occurrence, but these we need not now consider.

In the year 1580 a shock, sufficiently strong to set some of the church bells ringing and to cause loose masonry to rattle down from St. Paul's Cathedral and from the Temple Church, was felt in London. Nearly two hundred years later, in 1750, other shocks were experienced in the Metropolitan area; people rushed from their houses in the greatest alarm, and for some weeks much excitement existed. It was at this time that certain charlatans sold pills as an antidote against earthquakes. Every person who could do so made his way out of London, and those who remained encamped at Hyde Park and in the open land which then was plentiful round about the city. No earthquake shock of any note seems to have been recorded near London for more than one hundred years. In 1868 a slight shock was felt, and Charles Dickens recorded his impression of it thus: "It was as if a big dog was under the bed and trying to raise it with its back."

FIG. 3.—EARTHQUAKE AT WIVENHOE, ESSEX, IN 1884.

Scarcely a chimney was left standing, and in many cases the roofs were denuded of tiles and slates. Happily no loss of life occurred.

The most recent earthquake shock which was distinctly felt in London was that of 1884. The centre of disturbance was in the Eastern Counties, near Colchester, in Essex, and the damage caused in that neighbourhood was considerable.

At Colchester a church spire was broken off short and brought to the ground, many other buildings in the town suffering more or less damage. But it was at Wivenhoe, a few miles away, on the branch line leading to Walton-on-the-Naze, that the full force of the disturbance was felt. The place had the appearance of having been bombarded. Roofs had been entirely stripped of their tiles, there was hardly a chimney left entire, and the streets and quays were littered with *débris* from the houses (Fig. 3).

FIG. 4.—HOW NAGARA GAWA BRIDGE (JAPAN) WAS DESTROYED.
Note how this massive railway bridge has collapsed beneath the sudden shock.

Many instruments have been devised for the purpose of recording earth movements, some of them being of very ancient date. Such instruments are known as *seismometers*. One, of great age, is preserved in Japan, where a large number of these instruments have originated. It consists of a dome-shaped erection, around the circumference of which are a number of dragons' heads, each holding in its mouth a ball. Just below each head is an open-mouthed frog, which receives the ball which may be detached from the dragon's jaws above by any sudden tremor. Such detachment is brought about by a delicately poised vertical bar within the structure. On one occasion a ball was found detached when there had been no perceptible shock to cause its displacement, and the contrivance was ridiculed for its supposed false testimony, until it was found that a destructive earthquake had actually occurred at a distant place.

Many seismometers have been contrived, consisting of a number of upright columns, which are easily overthrown by the slightest jar, the idea being that the direction in which they fall will give an indication of the direction of the shock. Such contrivances have not been found to furnish any reliable data, the columns

being subject to a rotary motion and falling in different directions.

Another form of seismometer is found in a vessel filled with fluid, the wash of which against its walls will indicate the direction of the earth movement. It is said that in 1755, after the great Lisbon earthquake, lakes in Britain and also in North America were disturbed with motions unusual to them. A pool of mercury in a well six feet deep, with appliances for noting any movements to which the surface of the liquid may be subjected, is the principle of an instrument which has been in use for many years in the South of France. A somewhat similar instrument is at the Paris Observatory.

The pendulum has been used in various forms for indicating or measuring minute earth movements, and has probably been brought to the point nearest perfection in the construction of Professor Milne's seismograph. The pendulum is placed horizontally, and is like a ship's boom supported by means of a vertical mast. The whole arrangement is attached to a masonry column, so that it may not be affected by mere local vibrations. At the end of the boom, or pendulum, is a small mirror, which reflects the light from a lamp, through a slit in a box, within which is a ribbon of sensitive photographic (bromide) paper, which is kept constantly moving by the aid of clockwork. So long as the boom is kept perfectly still the record on the paper slip, which is wound on a drum, takes the form of an unbroken line: but a shock of earthquake will cause the pendulum to vibrate, the mirror partakes of the movement, and the spot of light thrown into the box executes a series of lateral movements which are duly recorded

FIG. 5.—REMAINS OF SARCONI CHURCH.
(From Robert Mallet's "The Neapolitan Earthquake of 1857.")
(By permission of Messrs. Chapman & Hall.)

upon the paper after the latter has been through the necessary developing process. By aid of this instrument Professor Milne has detected at his laboratory in the Isle of Wight earth movements which have had their origin at the Antipodes, so highly sensitive to vibration is the contrivance. He thus gets notice of a distant earthquake long before news of it arrives in this country by telegraph.

Photo: J. Winterton, Junr.

FIG. 6.—PLAZA OF PALMA, GUATEMALA, AFTER AN EARTHQUAKE.

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